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A CYBERNETIC APPROACH TO ACQUISITION SYSTEM PROGRAM OFFICE MANAGEMENT: PRELIMINARY CONCEPTS AND PROCEDURES

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THESIS

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Preface

Goldratt states that the greatest compliment one can give is to call something common sense -- which means no more or less than that it meets the tests of logic and experience intuitively. Cybernetics indeed reeks of common sense. However, one is cautioned not to believe that its usefulness is thereby lessened ... the power of the theory to provide a basis for proactive management appears strong and promising.

Management cybernetics is a young, cross-disciplinary science -- proven by the mathematics of logic, set theory, and statistics -- developed by students of communication, biology, statistics and mathematics, as well as management -- to provide a means of making truly informed decisions regarding any system too complex to fully determine its every behavior.

Applications of cybernetic thought have been implemented within governments and institutions around the globe; however, it may well demand more of an investment of creativity and change to gain wide spread acceptance. Although I have not yet studied the mathematical basis of the theory, and feel that I have only begun to understand the means to apply cybernetics usefully, I am convinced that cybernetics offers unmatched richness and insight. Does that statement mean that I am biased? Perhaps, but biased by my own experience with its application to and usefulness in everyday life ... and the greater insights

these experiences have provided. I encourage the skeptic to read, at a minimum, Platform to Change by Stafford Beer, and perhaps Applications of the VSM edited by Raul Espejo who worked with Beer in Chile, and try its thoughtful application to your own experiences before you reject either the theory or its applicability to the real world.

It is my fervent hope that others will accept the challenge of cybernetic study and add to the knowledge of its application to the US government which I have barely begun. I believe the warnings for us are strong and frequent ... and pray there is enough time to heed them.

There are several people to whom I am deeply indebted for their wisdom, guidance, and support during this research endeavor. First, to the TEACHER who introduced me to the ideas of Stafford Beer and my thesis advisor, Dan Reynolds: a heartfelt thanks for the challenge and enthusiasm ... truly inspired me to learn and grow. In addition, I never would have made it this far without the continual support, inspiration, and guidance of my colleague and friend, Dan Vore, whose intuitive grasp of the complexity, patience, ability and willingness to guide me clearly and gently in pursuit of knowledge and truth, and belief in me made all the difference. Lastly, and most importantly, I thank my husband, Bruce, for his love, tolerance, and understanding throughout the last year and a half as I struggled to learn enough to complete this effort -- I know it was neither easy or fun -- I am most indebted.

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Abstract

This ~~effort~~ considered the application of management cybernetics principles of organizational structure and tools of measurement and analysis espoused by Stafford Beer, in concert with the Theory of Constraints of Eliyahu Goldratt, to the USAF acquisition System Program Office (SPO). An extensive review of the literature was conducted, and the theories of cybernetics and constraints were summarized. In short, cybernetics identifies the necessary and sufficient structural conditions required of an organization to assure its viability and offers an alternative to current "fire-fighting" management using computer analysis of critical measures of performance to provide accurate short-term forecasts. A preliminary cybernetic analysis of the SPO organization and measurement tools was conducted, using data from the DSCS SPO, initial recommendations for improvement were derived from SPO members, and impedances were considered. Cybernetics appears to be a promising aid to program managers, providing insight into organizational structure and offering a means to truly anticipate, and therefore take action to avoid, problems. However, much additional research is required before specific beneficial procedures for the SPO can be recommended, and DOD policy changes are needed to facilitate the implementation.

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I. Introduction

General Issue

The media continually report examples of management failure in industry and government. Bankruptcy, government bail-outs, massive lay-offs, defective products, environmental disasters seem to grow in number and frequency almost daily. Although no clear path out of the current situation is recognized generally, the demands of the market and the public interests have driven industry and government to actively seek solutions to these ills.

What distinguishes those organizations which have been successful from those which have failed? What are the tasks and responsibilities of management to that end? Every manager has some intuitive sense of what constitutes success. However, many have sought additional insights from the experts. Countless books and articles have been written and seminars offered advocating NUMEROUS approaches intended to improve management effectiveness. The more popular can be defined by a single catch phrase -- "Management by Objective", "Total Quality Management",

"Quality Circles", "Excellence" -- and offer a limited number of straightforward tenets or procedures to follow -- "14 Points", "Eight Basic Principles", "Just In Time", "semiautonomous work teams" -- derived in general from intuition and personal experience or empirical study of successful companies and organizations.

There is no popularly advocated theoretical foundation upon which to base or judge any of these approaches. Without such a foundation it is merely supposition whether any or all of the proposed (partial) solutions to the current management 'crisis' are indeed necessary and sufficient to truly provide managers with the ability to control the systems which they are charged. At best managers manage by trial and error and even if successful do not know if there is still a better way; at worst they do not manage at all and the system fails to achieve its purpose or in some cases even to survive. When the early scientific management theories of Frederick Taylor et al proved inadequate to maintain a motivated, productive work force, no alternative comprehensive management theory was recognized to replace it. Instead, the favored approach of various scientists, theorists, and empirical managers has been to study and recommend solutions to such more narrowly focused questions as "How do we keep employees highly motivated?", "How can we keep ahead of our competitors in the marketplace?", "How do we develop leaders?", How do we

provide better quality at a competitive price?". Not only do such "answers" leave the manager to try to mesh the various pieces/approaches together, they do not answer such basic questions as "Are there indeed common characteristics necessary and sufficient to ensure any organization's "success", "What constitutes success", "How does an organization retain its ability to succeed over time". While relatively simple to teach and learn, and as desirable as the recommendations may be, the continued succession of popular approaches indicates that managers are still searching for answers to help them resolve their own current management crises.

Management within the government is a subject of much concern because of the pervasive impact poor management can have on the country's economic, social, and political stability, and the effect it could have on the entire world. In particular, the United States has come under increasing criticism from its own people and Congress, as well as from many in other parts of the world. Although one could readily argue that all areas of US government are not currently managed optimally, no department has undergone more scrutiny and critique than the Department of Defense (DoD). Because of its relative cost and the publicity of its failures, much of this attention has focused on the management of new weapon systems acquisition by components of the DoD (10:31-32). Each component service

has similar, but not duplicate, procedures, precedents, and initiatives which drive their acquisition process. For convenience, the Air Force will provide the focus for this discussion.

At the center of Air Force acquisition process are the System Program Offices (SPOs), each run by a program manager responsible to " contract for and oversee the development and production of weapon systems and equipment on time and at reasonable cost" (10:9). Each SPO organization is a complex, dynamic system which must fulfill its tasks, directed ultimately by Congress, in the midst of the very unstable, bureaucratic, and environment of the military industrial complex. SPO success is measured by its ability to provide the weapon systems for which it is responsible to the unit which will operate the system at an agreed to cost, schedule and performance baseline. Its ability to conform to this baseline is directly effected by the program manger's ability to effectively structure his organization and to maintain a stable baseline, which includes determining how changes in user requirements can be incorporated in the existing program, retaining adequate funding from Congress, controlling the timeliness and correctness of SPO activities, and controlling contractor performance. In order to achieve these ends the SPO must be able to anticipate and avoid potential problems inherent in the

risks of the acquisition process. Risk stems from the focus on new sophisticated technology, optimistic and often concurrent schedules required to meet predicted threats, and constrained and often changing defense budgets (10:152-154).

SPO success in managing acquisition programs in the current environment of escalating Congressional management by legislation and frequent budget changes, increased DoD regulation of its own and industry's management practices, in response to public concern about much publicized failures, has generally been criticized by Congress and the public. J. Ronald Fox quotes retired Army General Miley who explained,

> ... perception is that at least some of the programs were not as successful as they could have been. Further, there is a perception that the quality and performance of the project managers have been contributing factors. The accepted indicators of the less than reasonable success of the programs have been the highly publicized reports of system deficiencies, cost over-runs and delayed fielding. (10:154).

In a series of attempts to improve the management of acquisition programs in response to this criticism, DoD leaders have tried to encourage process improvement through adoption of the most popular industry management philosophies, including management by objective and, most recently, total quality management. However, since the under-riding structures and incentives were not changed, the improvement programs could produce no major change to

the acquisition process and seemed merely rhetoric to the SPO (10:51).

If changes to the organizational structure and performance incentives are required to motivate fundamental change as current organizational theory maintains (6), one needs a basis upon which to determine what to change, and what to change it to (12:9) to obtain better results.

A lesser known succession of scientists, mathematicians and managers have developed an alternative management theory and practice over the past forty years which offers not only a theoretical basis for assessing existing management tools and systematically identifying new ones but also a general model of organizational structure, functions and interrelationships by which one can diagnose the current state of any large, complex, probabilistic system and proscribe changes to increase its likelihood of long term viability. The field is management cybernetics, detailed by Stafford Beer et al, out of the initial work in Cybernetics by Wiener, Shannon, and Ashby in the 1940's and 1950's.

Cybernetics confines its application to large systems for which the implicit notion of Taylor that management can indeed know everything about the operations for which he is responsible and environment with which he must obtain inputs (ie. resources, requirements) and provide outputs (ie. products, services) is not true. Briefly, cybernetics

has at its core a two step premise that (1) any system transforms "inputs" into "outputs", and its organizational structure determines which outputs are most likely under various conditions. Thus, by recognizing what functions and interrelationships are necessary within any system using the Viable System Model developed by Stafford Beer, a system can be reorganized to increase its effectiveness; and (2) although all the details of the past, present and future of any complex system can never be known, the relationships between various system inputs and outputs can be measured and used to identify areas in need of attention and correction -- thus it provides the manager with ONLY the information he needs, and it provides it fast enough that he can take corrective action before the situation is out of hand.

Therefore, the most basic characteristic of management cybernetics is that it relieves the manager of the impossible task of knowing everything about everything that occurs in the systems for which he is responsible by taking advantage of technology to identify outcome trends and probabilities without the delay and information overload inherent in current information systems. Thus, cybernetics provides the framework to allow the manager to do what has always been demanded of him: to anticipate troubles and avoid them before they occur to ensure planned performance is attained. Although the approach is more intensive and

consequently has not generated much public appeal, documented applications indicate that it may well provide far better answers to the needs of today's management of civilian and government enterprises (8).

To avoid being limited to considering generalities, support from the Defense Satellite Communication System (DSCS) Program Office was secured to provide a specific case for study. Discussions between the author and the SPO (cite) led to agreement that the effort would focus on the contract modification process which is central to the SPO current efforts. Briefly, the process begins with the identification of a new or changed contractual requirement, follows through funding and approval, request and review of the contractor's proposal, fact-finding, negotiations and ends with contract award (13; 16; 17). Description of the SPO and modification process will be detailed as the analysis and findings of this research effort.

In summary, then, the management question is: How can the principles of cybernetics be applied to a SPO, using the DSCS SPO as a case study, what do they indicate about the SPO's current effectiveness, and what improvements can be recommended?

Specific Problem

There are many circumstances which create the environment in which current SPO management function: oversight, and cost, schedule and performance uncertainty.

The clearest picture of the current state of oversight within the acquisition process is painted by the number of regulations published by Congress, OSD, and the AF; as Fox describes, "a team planning a weapon system must conform to over twelve hundred directives concerning all phases of the acquisition cycle" (10:17). Meeting the unique challenges of a major acquisition program, within the confines of that many regulations, and having time to manage the program while providing briefings and reports to the various management levels to demonstrate compliance with those regulations (10:160) severely limits the time and talents of the program manager. In addition, the changing priorities of the decision makers in response to changes in the perceived threat, the defense and political benefits and costs of various means to address the threat, and the salability of these various means to other decision makers, results in "frequent changes in funding, schedules, and technical performance requirements" (10:19).

Specifically, then, the SPO, as the system acquirer, is at the heart of a very complex, ever-changing process. As Fox explains, "It is virtually impossible for any individual ... to comprehend every aspect of ... a major acquisition program" (10:11). To date, most SPO's ability to meet its baseline under these conditions has been sporadic at best. For instance,

> schedules have been extended by about 33 percent in approximately one-half of the

> programs ... more than nine in ten programs exceed initial cost estimates, and the average increase in cost for the majority has been more than 50 percent, excluding the effects of quantity changes and inflation (10:33).

With these statistics, and the public outcry for reform, it is necessary to explore every means to restructure the SPO acquisition structure and control performance.

To demonstrate the application and potential usefulness of management cybernetics to SPO management in this regard, an organizational model of the DSCS SPO and a process model of the SPO modification process must be developed. The organizational model must be developed in accordance with the VSM to diagnose pathologies in the current structure, policies, procedures and information channels and prescribe changes to increase the viability of the SPO. The quantified flow chart will be used to identify bottlenecks and variables critical to the process and to which management must direct its attention to maintain the viability of the system. Based on the results of the flow charting, an initial design of the measurement tools to proactively control the modification process will be suggested.

Justification

The legacy of the current acquisition structure on SPO performance has been well documented. Between the direction and oversight from Congress, DoD, and the AF, and the independent plans and agendas of the defense industry

participants, the program manager has found himself without much autonomy or authority with which to control any part of the acquisition process in a substantive way (10:18-19,154). However, he, and every level of management above him, is held responsible for meeting or failing to meet the baseline cost, schedule, and technical performance (10:156). Packard is quoted as saying,

> the fact is that there has been bad management of many defense programs ... part of this is due to basic uncertainties in the defense business ... However, most of it has been due to bad management, both in the DoD and in the defense industry ... (10:134)

Consequently, if the situation is to improve, managers must obtain the tools to restructure his organization and to regain control of the operations for which they are responsible. As described earlier, cybernetics provides just those tools. The principles of cybernetics offer a unique perspective from which to view how organizations actually behave, to assess the current performance of that organization against the ideal, and to recommend changes to the organizational structure which will necessarily improve the organizations performance. In addition, cybernetics offers measurement and analysis tools with which to monitor and control systems without needing to know everything that occurs within the system.

Given the current defense budget environment of severe spending and personnel cutbacks which is expected to continue into the foreseeable future, it is imperative that

all potential tools to improve the process of acquiring weapon systems be explored. Although cybernetic modeling has been a published management tool for over 30 years (9; 18), no evidence of its specific application to defense systems acquisition office management was identified through a Defense Technical Information Center (DTIC) search. Consequently, there is a need to apply this tool to the SPO management process to assess its usefulness to the SPO manager in processes of defense system acquisition. The current concerns of the DSCS SPO provide a supportive environment in which to apply cybernetic modeling techniques (13; 16; 17).

Research Hypotheses

1) The functions and interrelationships of the DSCS SPO can be mapped onto Stafford Beer's paradigm of any viable system (4; 5) to create an organizational model of the SPO to diagnose its current viability.

2) The organizational model can be used to prescribe changes to SPO functions and interrelationships which may improve SPO viability.

3) A quantified flow chart can be developed for the DSCS SPO modification process and used to identify process bottlenecks, and critical process variables (2).

4) A simple design of the measurement tools to proactively control the modification process using critical variables can be suggested (2; 3).

Scope and Limitations

The scope of the research is restricted to accurately modeling the DSCS SPO functions and interrelationships and the modification process to demonstrate the type of effort needed to initiate cybernetically sound management within a SPO. This effort will provide the basis for additional cybernetic study by the SPO and for similar efforts by other organizations; it will not consider non-cybernetic theories. Cybernetic management requires a process of continual adaptation to maintain stability. Thus, the models are limited by the lack of continual and complete data collection inherent in an outsiders study and by their relative simplicity. Clearly, models of all SPO activities as an interconnected whole would need to be developed and updated daily to provide a truly useful management tool. Throughout the effort the reader is assumed to have a basic understanding of the AF acquisition process and SPO operations.

II. Management Cybernetics

Overview

Cybernetics offers a systemic perspective to the management process and two basic tools for the manager's use. Once the basic principles of cybernetics are understood, they provide a framework for study and control of the organization.

The Viable System Model (VSM), proposed by Stafford Beer, identifies the functions and interrelationships of any complex probabilistic system which can be used to diagnose and prescribe treatment for any organization to better ensure its long term viability, by enhancing its ability to adapt and evolve (4:xii). Control of the organization is facilitated by a unique management information system (MIS) which combines process modelling, continual measurement and statistical analysis to forecast near-term instabilities in the current operations and to consider potential future events.

Principles

The most basic purpose of any system is to remain viable, to continue to survive within its environment in the face of both expected and unexpected events (4:18; 5:113). Although each system is made up of a unique set of entities, be they cells, machinery, or humans; viewed as a whole, a system's viability is determined by its inherent

ability to adapt to changing conditions to maintain the stability of its essential characteristics -- the essence of regulation (4:ix). This concept becomes more apparent if the system discussed is a human who uses his mental and physical skills to adapt to changing conditions in order to stay alive; a state which it achieves as a function of its systemic design (vice continual conscious effort) to maintain its critical variables such as blood pressure, temperature, pulse, brain wave patterns, for example, within some range of acceptable limits (4:109). Ashby, Beer and others have discovered that any complex probabilistic system, such as a social, industrial, or governmental organization, can be viewed in exactly the same way, because all systems are subject to the same "laws or principles of control" (4:ix). Beer explains, "the laws of viability in complex organisms are ... primarily concerned with the dynamic structure that determines the adaptive connectivity of their parts" (4:xi). These invariances among systems are the subject of cybernetic study (1; 4:13; 5:309) which entails two management foci: organizational structure and systemic control (via measurement and data filtration) (4:ii).

Management cybernetics is defined by Beer as "the science of effective organization" (4:xi). And while he acknowledges the applicability of many other scientific disciplines to management, he emphasizes that "if the

structure is dysfunctional then no amount of financial wizardry, of business technique, will save the day" (4:x). Many might question the applicability of science to a field as full of unpredictability as management seems to be, but Goldratt offers a strong argument that management is indeed a science. To this end he identifies three stages that every science goes through during its evolution.

The first stage is that of "classification" in which a unique vocabulary is developed; the second stage is that of "correlation" in which data is collected, from which relationships among things are discovered, from which assumptions and "laws" are derived. He points out that in both of these stages, the only "proof" is to try something and see what happens. There is no understanding as to why things relate as they do until the third stage, "Effect-Cause-Effect". It is this third stage, generally recognized as "modern science", in which an understanding of the underlying causes allows one to derive knowledge of new situations through logical deduction, vice experience alone (12: 23-26). With this in mind, Goldratt provides a useful definition of science, saying

> ... the widely accepted approach is to define science as the search for a minimum number assumptions that will enable us to explain, by direct logical deduction, the maximum number of natural phenomena. (12:23)

One example of the stages of science which Goldratt provides is that of disease; in which first diseases were

"classified not only by their symptoms but also by their ability to infect others" (12:25); the second stage began when Edward Jenner discovered the usefulness of immunization centuries later, and the third stage was not begun until Louis Pasteur discovered the existence of germs, which allowed the evolution of modern medical diagnosis and treatment (12:25-26).

Obviously, management is a much younger science. Clearly, it has its own vocabulary which allows classification of management phenomena (stage one). Just as clearly, the host of management approaches demonstrate that significant correlative work has been accomplished. By observation it has been discovered that more successful organizations seem to have some common traits which the "14 Points" of Deming or "8 Basic Principles" of Peters & Waterman, to name two examples popular within Air Force circles, attempt to isolate (stage two). However, without an understanding of why these correlations exist it is impossible to deduce how to effectively manage an organization as an entity because the correlations discovered to date may only apply in certain circumstances or may require the presence of additional criteria as yet unknown; just as before doctors had an understanding of microbiology they were severely limited in their ability to help a person adapt to disease and maintain or regain his health. Some treatments, like immunization, worked and

some, like leeching, did not. Once stage three was reached, not only was the accuracy of treatment greatly improved, but also it became possible to react to new situations (i.e., to find reliable treatments for new diseases) (12:26).

Management cybernetics has identified the mechanisms (functions and interrelationships) of the organization (3:124-125), just as microbiology identified the mechanisms of disease and may well provide the means for a truly holistic approach to management (4:120) which provides scientific predictability while fully acknowledging the diversity and complexity of people and interactions within any organization.

Management cybernetics defines a system by what it does (4:99); for example, a school may have the purpose of creating new knowledge, or imparting old knowledge to new students, or solely providing day-care services; one can tell what its purpose is by observing what it is "producing" (i.e., research, knowledgeable or illiterate graduates). If the intended purpose does not equate with the actual purpose as demonstrated in the actual outcomes, one must change the system until its outcomes meet the intended purpose. In effect, Beer argues that a system's design determines its likely outcomes and must be consciously redesigned using the VSM if different outcomes are to be achieved.

Any system has three main components: management, operations (that which actually produces outcomes), and the environment, each embedded in the next and linked by communication channels (Figure 1) (4:27; 5:94). Cybernetics' power is derived from its ability to treat each component as a "black box", whose inner workings can not, and need not, be understood, focusing instead on their interactions (4:46). By studying the relationships between inputs and outputs, the functions of each component can be discerned, and changes in inputs can be made to alter the outputs as desired (5:40). Although such a concept is quite unusual within organizational management theory, it is common in practice (especially dealing with other individuals) and offers the major benefit of not demanding that management know everything that goes on within his organization and its environment. This implicit demand of orthodox management practice has resulted in the current craze for information -- as much and as often as possible -- more than the manager needs and more than he can assimilate. Cybernetics offers the means of discovering what information management truly needs so that he has the ability to predictably effect the results of the organization and the freedom to plan and guide his level of the organization (5:40-42).

Beer defines the job of management as that of managing complexity. In this sense, complexity subsumes the

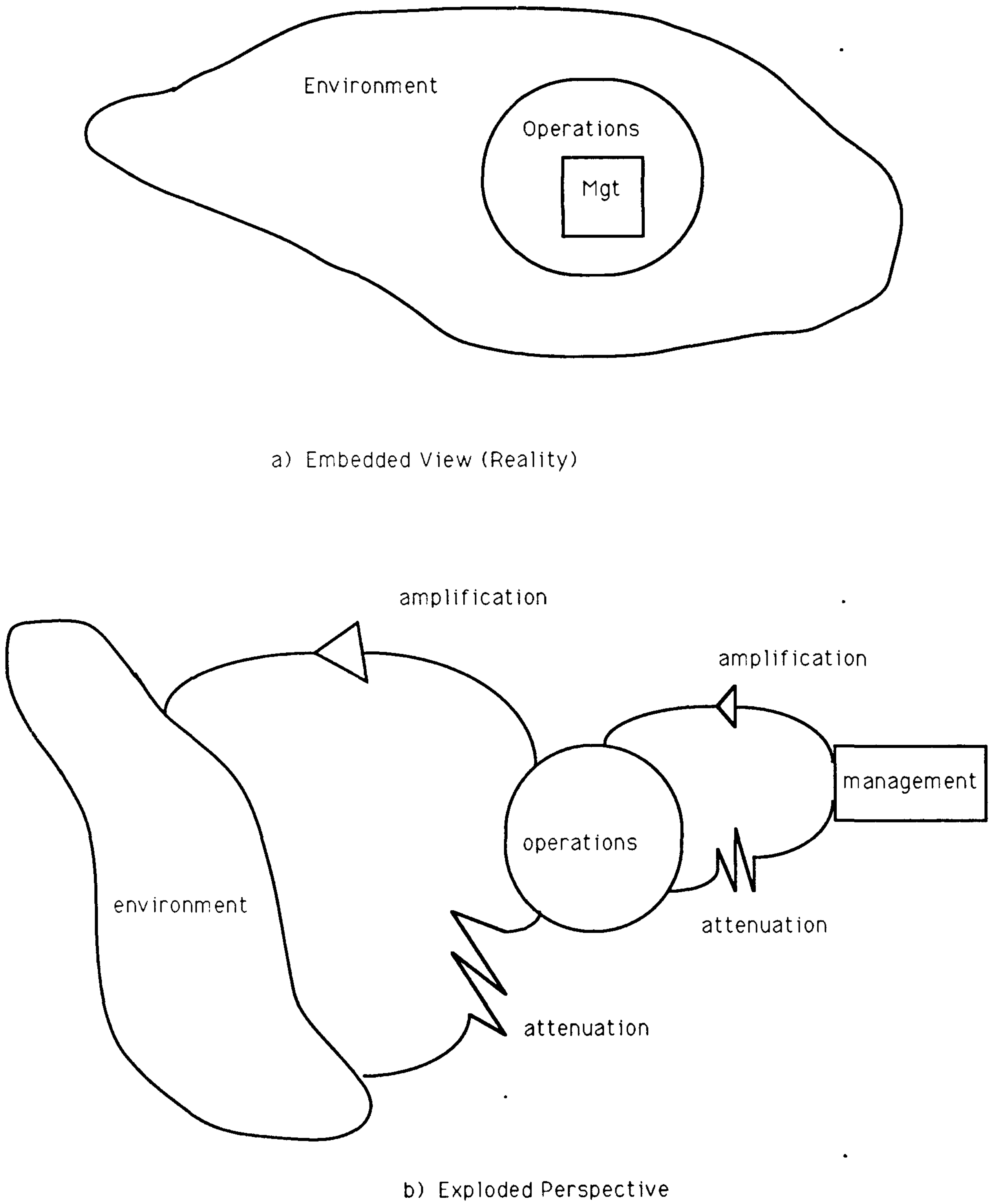


Figure 1. Simple System Model (adapted from 8: 57,59)

traditional management foci of "men, materials, machinery and money" (4:21; 5:31). The complexity of a system can be measured (qualitatively) as the number of possible states it can achieve. A state is defined by its being recognizably different from some other state of the system; in the terms of mathematics, each state has a unique set of parameter values. The measure of the number of possible states is called variety (4:21; 5:32). For instance, the variety of a person is the list of all possible sequences and mixtures of activities, moods, and thoughts he could conceivably conduct. However, any particular individual will have an actual variety which is much less than that conceived of theoretically because physical, mental, philosophical, and other parts of his "makeup" limit what he will actually do, think, say, and feel -- his self-organization limits his variety. Similarly, the variety of an organization is limited by the actual variety of its members and their interactions.

It is clear that the variety of management is much less than that of operations which is much less than that of the environment (4:22; 5:94). Fortunately, it is inevitable that the structure (people, policies, procedures, and interactions) of the environment and of the operations organize themselves, in a mixture of formal and informal procedures and interactions, so that the actual variety observed by operations and management, respectively, is

more constrained than could be envisioned in theory. As Beer explains, "variety absorbs variety, and systems run to homeostasis because all the subsystems are interconnected ... and complexities cancel each other out" (4:30). Indeed such self-organizational forces tend to equate the environmental, operational, and managerial varieties, but without conscious design, may not secure the organization's long-term viability. For example, a process may require action by several offices; if one begins to be avoided in practice (self-organization at work) because the activity is perceived as no longer required or a new person in the position is not liked or trusted, the results of the organization will suffer -- outputs will be less predictable and not in keeping with the goal of the organization (assuming the activity was in fact value-added). Management's fundamental task is then to regulate variety, in part by design of competent organizational structures, so that the system is not overwhelmed by complexity and can maintain its viability in pursuit of its declared purpose (4:29; 5:92-97).

Ashby's Law of Requisite Variety, the most basic law of cybernetics, which states that "only variety can destroy variety" (1:207), provides the basis for management activity. This law explains the inevitability of variety equilibrium between every pair of entities, components or subsystems (5:89). The derivation of this law is based in

the mathematics of transformations and the theory of communications (1; 8:13,16-18), but the law, because it is operative (5:89), can be observed without analyzing the formal proof. Noting that there is a slight distinction between information and variety -- the variety of an entity is a state of its existence, known to another entity when it receives this information from the first (8:82) -- the two terms will be used as if they were interchangeable.

Clearly, there is a limit to the amount of data any one person can process; how does a person cope with the overwhelming amount of information with which he is faced? He ignores the majority, either by conscious choice or by necessity when he reaches an "information overload" (5:100), but, knowing his limits, he may devise techniques to increase his chances of receiving and processing all the information he needs before his capacity is reached, by filtering out system noise. This simple example not only demonstrates the operation of the Law of Requisite Variety but also illustrates the two mechanisms, attenuation and amplification, by which variety equilibriums are maintained (5:92-97). Variety of the more complex subsystem in excess of what the less complex subsystem can "handle...is necessarily cut down, or attenuated ... attenuation just happens. The brain and managerial culture ... filter out what is left in beyond the capacity to assimilate" (4:23-24). Conversely, the variety of the less complex

subsystem "is necessarily enhanced, or amplified" (4:27) to the level necessary to regulate the more complex subsystem using techniques which facilitate the flow of necessary information to the less complex subsystem in an easily processed form (5:90).

The significance of the Law of Requisite Variety is plain: "every attenuation of variety risks the loss of vital information, or the introduction of ambiguity" (D:120). Since variety of an operation, for instance, in excess of the variety of its management, is of necessity attenuated, it is clear that management must consciously design variety channels between itself and its operations and their environment(s) if the right information is to be available to the right people in time to maintain the system's viability (5:97-100); design by happenstance or convenience will not provide the best means to manage the system (5:97; 9:15). A monthly management report is a simple amplification/attenuation device; the variety of the manager is amplified when the types of information he needs and the format he prefers are provided in the report, while the variety of the operation is attenuated dramatically. However, the attenuation and time-lags inherent in such traditional reports are often too great to provide sufficient information to the manager (5:297). The design of more powerful attenuator/amplifier combinations will be discussed toward the end of this chapter.

The final introductory concept which must be presented before the VSM can be described in detail is that of recursion. Beer likens the concept of recursion to that of chinese boxes, each containing and contained in another (5:118). Each system is contained in and contains others along each of its dimensions. For example, a person is a system within each of his dimensions (family, company, whatever other organizations he may be a part of); for each dimension, the chain of systems can be laid out from the system of the cell (or viable part thereof), to the system of the world (or universe) at the extremes (4:4,6). Whatever system is of interest is called the "system-in-focus", defined as a single level of a dimensional recursion. Beer and Espejo both emphasize that a clear understanding of purpose, and consequently the dimension of interest, is needed to determine the most useful boundaries of the system-in-focus (4:7; 8:363-364,369). Recursion emphasizes the invariance of systemic structure and activities among levels of recursion, while acknowledging their distinct "language" -- role, history, responsibility, and technology (4:110).

Organizational Structure (VSM)

Expanding on the initial system model (Figure 1), the VSM identifies the five functional subsystems and their interactions with each other and the environment which are essential to maintaining the viability of any complex

probabilistic system (Figure 2) at every level of recursion.

SYSTEM ONE consists of one or more viable systems at the next lower level of recursion, perceived at the level of recursion of the system-in-focus as an interconnected set of operational units (represented by circles in the VSM) and their individual managements (squares). Thus, SYSTEM ONE at one level of recursion represents the totality of the next lower level of recursion and constitutes a major link (information channel) between the two levels. It should be noted that SYSTEM ONE activities are only those which produce the organization -- those which continually reproduce its identity, or purpose -- all supporting activities are part of management which Beer calls the metasystem (SYSTEMs TWO through FIVE) which is dedicated to the homeostasis of the system-in-focus (4:9). For example, for an accounting company, accounting is SYSTEM ONE; however, in a manufacturing firm, accounting is part of the metasystem and production is SYSTEM ONE. The operational units interact with each other and directly with the environment; in addition, the environments of the various operational units overlap. Each subsidiary viable system is essentially autonomous: constrained only to the extent that it remains a part of the system-in-focus. In this regard it is constrained in three ways: it must operate within the intentions of the system-in-focus, within the

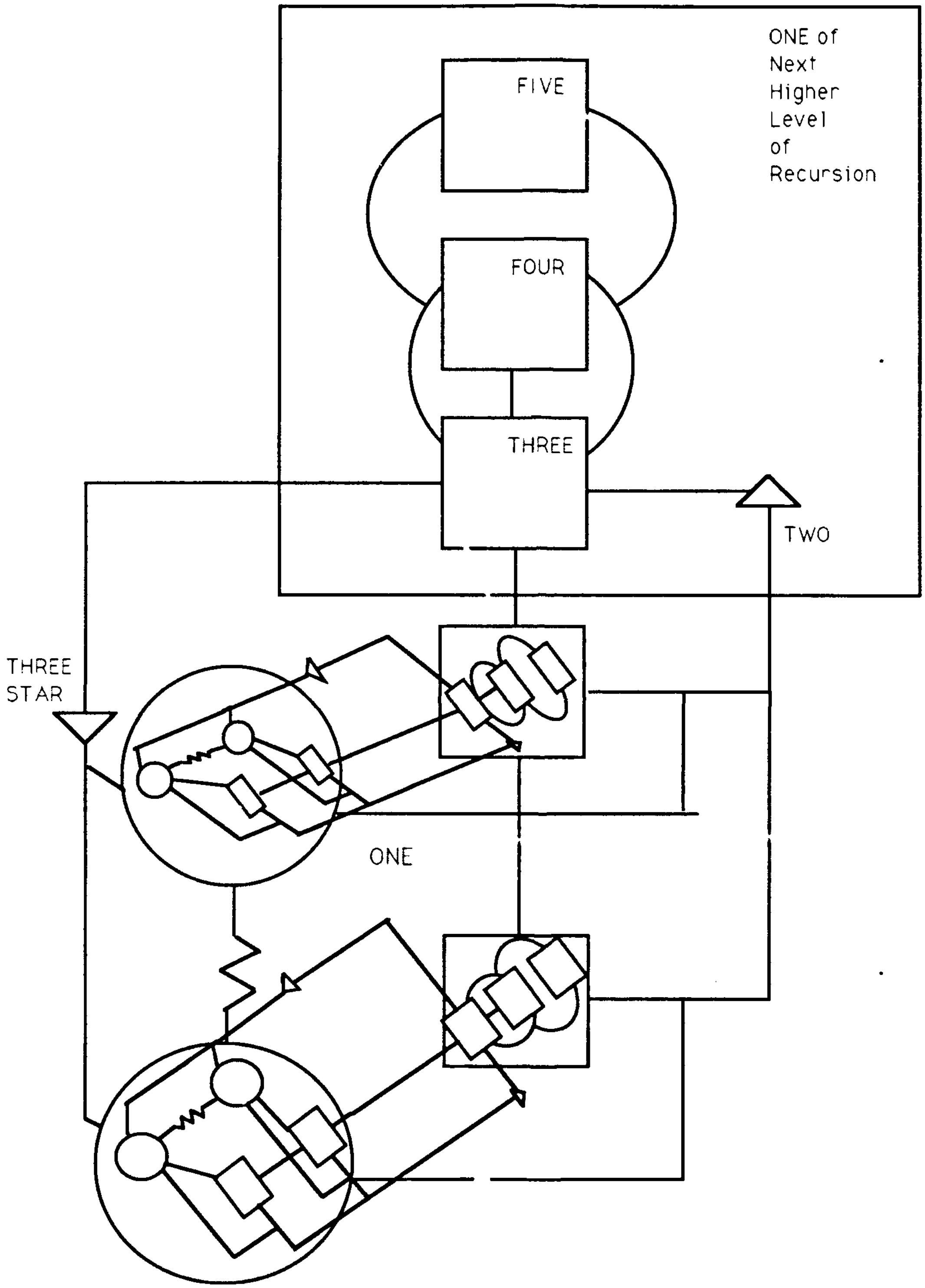


Figure 2. The Viable System Model (adapted from 4:136)

regulatory framework of SYSTEM TWO, and under the direction of SYSTEM THREE (2:158-161).

SYSTEM TWO is the regulatory center of the system-in-focus which quells the oscillations inherent within SYSTEM ONE as a whole, caused by activities of the environment, operation, or management of one subsidiary viable system which impact the environment, operation and management states of one or more others. Oscillations are often caused by a lack of policy, so that each subsidiary viable system acts, not in concert with all the others, but autonomously, to the potential detriment of other parts of SYSTEM ONE (4:73; 2:172). The SYSTEM TWO functions are not part of the command channel, but rather serve SYSTEM ONE, providing the means to maintain the stability of SYSTEM ONE by implementing policies and procedures (such as work scheduling, professional protocol, or a corporate identity) seen as necessary by SYSTEM THREE to implement the "resource bargain" (4:66-79). Note that each subsidiary viable system has a regulatory center which maintains the homeostasis between that system's management and operations (4:41) and communicates with the SYSTEM TWO of the other subsidiary viable systems to prevent conflicting operations (2:174); these, however, function at the lower level of recursion (4:68). In addition, SYSTEM TWO transduces the information from SYSTEM ONE into the language of the metasystem (H:318-319).

SYSTEM THREE provides the day-to-day management of the system-in-focus and has two basic functions as governor of the "stability of the internal environment of the organization" (2:175-176). The first is to command and make decisions regarding SYSTEM ONE as a totality. SYSTEM THREE and the management of each subsidiary viable system of SYSTEM ONE have a mutually agreed to "resource bargain" wherein SYSTEM ONE performs a number of programs with the resources given it by SYSTEM THREE (4:37-39,86-87). In return SYSTEM ONE is accountable to SYSTEM THREE for completing its assigned programs. In addition, SYSTEM THREE intervenes in SYSTEM ONE by requiring compliance with some minimum number of corporate rules and regulations (4:39-40). Thus, there are two homeostatic loops between SYSTEMs ONE and THREE along the command axis -- the resource bargain - accountability loop and the intervention-obedience loop (4:56). The second task of SYSTEM THREE is to enhance its own capacity to absorb variety (4:94) by monitoring SYSTEM TWO (4:86) and by conducting sporadic internal audits of the operational units directly -- a function which Beer calls SYSTEM THREE STAR (4:82). Both the variety increasing channels provide means of obtaining additional information to supplement and confirm the information received from SYSTEM ONE via the accountability channel. It should be noted that several persons or groups of persons may comprise SYSTEM THREE:

there may be, or need to be, homeostatic loops among some or all of them (4:93).

While "SYSTEMs TWO and THREE are concerned entirely with the regulation of SYSTEM ONE" (8:343), SYSTEM FOUR "handles the interaction of the whole viable system with the outside world" (8:343). SYSTEM FOUR comprises the "set of activities ... which feeds the highest level of decision making" (2:183), using models of the system-in-focus and knowledge about the environment to simulate possible organizational futures. SYSTEM FOUR continuously monitors the environment for trends and novelties using a filtration system which "recognizes pattern in the unknown (but developing, imminent) future" (4:124). This study of the relevant environment, relative to the system-in-focus, is used by the SYSTEM THREE, FOUR, FIVE metasystem in its continual planning process. Since SYSTEM FOUR maintains models of the system-in-focus it provides self-awareness: an understanding of the dynamics of the system itself (4:116); the degree of accuracy of the model and subsequent understanding of the organization is a strong indication of the system's ability to adapt, and thus survive in the long-term.

SYSTEM FIVE is the "boss" who intervenes as necessary to maintain the homeostatic balance of investments (of "money, ..., time, care, talent, attention, reward" (4:118)) between SYSTEMs THREE and FOUR necessary for adaptation.

As the ultimate authority for the system-in-focus, he (they) may provide command direction, but for the most part, act(s) as a "variety sponge" (4:125), by projecting an ethos for the system and thereby precluding a multitude of possible occurrences which are not "acceptable", which violate the atmosphere of the organization (4:124-130).

In order to facilitate the high variety interaction between SYSTEMs THREE and FOUR and the real time reporting from SYSTEMs ONE and TWO, all within the atmosphere and guidance of SYSTEM FIVE, Beer strongly recommends that the management work place be a "Management Center" which he defines as the "environment of decision in which the board or college of managers reaches out into the process for which it is responsible" (8:352). He likens the management center to a continual board meeting in which real time information is available to the managers as a whole, breaking down the traditional barriers of space and time which hamper management interaction and therefore the potential for informed, synergistic decision making (8:355). Beer advocates visual representations of information as richer and easier to assimilate than words and numbers (2:194-195).

Specifically, the management center would contain four wall size computer driven screens, each to consider different aspects of the system. One would be "a large, electronic display" (2:194) of the organization's structure

mapped onto the VSM showing the proportional amounts and rates of flow (in terms of interest to the management) among the SYSTEMs. Areas in need of management attention would be signaled on the screen as they are identified through the measurement process. The next screen would provide the means for managers to call up additional information about the areas signalled as potential trouble spots. Again, this information would be graphic, in the form of process flow diagrams and time series charts, available upon request from the computer (2:194-195). The third screen will allow access to any information about the future gleaned from statistical analysis of environmental factors and the organization's levels of achievement: "Here we want the best prognoses which statistical technique and the insight of properly trained operations research teams can provide" (2:195). The fourth screen would provide a means of assessing the

> responses of the system to various alternative actions, in order to see which areas of a problem are more sensitive than others to the assumptions which management is making ... to test which policies are more vulnerable than others to a range of likely events (2:196)

in the future thorough simulation, using an interactive screen which allows the managers to input any combination of control parameters which the computer analyses using its statistical model of the organization and its environment and provides likely results on the screen. In this way, managers can conduct experiments and take risks (try new

ideas and novel approaches) without any impact to the actual system, and without getting bogged down in the mathematical detail (2:195-197). A more detailed consideration of the development of the computer information which would feed each of these screens is discussed in the measurement and filtration section of this chapter.

Optimally, an organization should allow SYSTEM ONE the maximum amount of autonomy which will not threaten its cohesion. This balance between autonomy and cohesion demanded by the law of requisite variety has been captured in three axioms of management (Table 1) which identify the equations of variety across the system-in-focus. The variety of SYSTEM ONE is a directly proportional measure of its autonomy (4:102) which is equal to the sum of the "horizontal" varieties of the operational units. This variety must be matched by the sum of the six "vertical" varieties of cohesive force: SYSTEM ONE environmental interactions, corporate intervention and the resource bargain between SYSTEMs ONE and THREE, the interaction between operational units, SYSTEM TWO, and SYSTEM THREE STAR: note that the first five filter management information and the last provides any information filtered out by the first five which management needs (4:81-84). The manner in which this balance is met is a matter of management style -- dictatorial or delegative (4:95).

Table 1

Three Axioms of Management (5:217.298)

First Axiom of Management:

The sum of the horizontal variety disposed by n operations elements
equals
the sum of vertical variety disposed on the six vertical components of corporate cohesion.

Second Axiom of Management:

The variety disposed by System Three resulting from the operation of the First Axiom
equals
the variety disposed by System Four.

Third Axiom of Management:

The variety disposed by System Five
equals
the residual variety generated by the operation of the Second Axiom.

The variety of SYSTEM THREE resulting from the balance of cohesive and autonomic forces must equal the variety of SYSTEM FOUR. and the variety of SYSTEM FIVE equals the variety generated by the balance of SYSTEMs THREE and FOUR varieties (5:298: 8:34). In addition, the variety of SYSTEM ONE with which SYSTEM THREE must cope is equal to the "variety disposed by the sum of the metasystems" (5:355) of the next lower level of recursion (Table 2) (5:355: 8:34).

Table 2

Law of Cohesion (5:355)

The Law of Cohesion for Multiple Recursions of the Viable System: The System One variety accessible to System Three of Recursion x equals the variety disposed by the sum of the metasystems of Recursion y for every recursive pair.

As important to the maintenance of viability as the five subsystems of any system-in-focus are the connections among the subsystems of the system-in-focus and between each subsystem and its corresponding subsystem at the next lower and next higher level of recursion (review figure 2). Each linkage represents two opposing one-way communication channels, each with a variety and capacity of its own. In addition, every time a channel crosses a boundary, transduction occurs as the communication is translated by the sender into the language of he believes the receiving subsystem will understand (encoding) and then by the receiver as he decides what the sender intended (decoding) (4:47). For the system to be viable, each channel must have a capacity greater than the variety of the information which it must transmit per unit time to avoid the introduction of unresolvable ambiguities (4:43), and the variety of each transducer must be as great as that of the

channel in which it is contained (8:33) to avoid information loss.

In a viable system, each channel must be a self-vetoing homeostatic loop. Such a loop is a means of regaining equilibrium between the two subsystems it connects after the system has been disturbed in some way so that the system can maintain its stability. At equilibrium, each subsystem is in an acceptable state. When any subsystem enters an unacceptable state, those with which it is connected by a homeostatic loop change state, which causes the subsystems with which they are connected to change as well; thus, a sequence of systemic oscillations is initiated which must be damped if the system is ever to regain its stability. If properly designed, the "self-vetoing" aspect of the loops provides the means to damp oscillations by continuing state changes in a controlled manner until all the subsystems have again reached an acceptable, although not necessarily the original, state (4:63-65). If homeostasis is to be maintained, the rate at which equilibrium is restored "must match the mean rate of perturbation" of the system (4:120). Each homeostatic loop must obey the four principles of organization as described above (Table 3).

Table 3

The Four Principles of Organization (8:33)

The First Principle of Organization:
Managerial, operational, and environmental varieties, diffusing through an institutional system, tend to equate; they should be designed to do so with minimum damage to people and to cost.
The Second Principle of Organization:
The four directional channels carrying information between the management unit, the operation, and the environment must each have a higher capacity to transmit a given amount of information relevant to variety selection in a given time than the originating subsystem has to generate it in that time.
The Third Principle of Organization:
Wherever the information carried on a channel capable of distinguishing a given variety crosses a boundary, it undergoes transduction; the variety of the transducer must be at least equivalent to the variety of the channel.
The Fourth Principle of Organization:
The operation of the first three principles must be cyclically maintained through time without hiatus or lags.

Measurement and Filtration Systems for Management Control

Given a viable organizational structure, the manager must have means to assess system stability and to ensure all, but nothing other than, essential information is available to him in real time, if he is to control the system. To this end, management cybernetics offers a unique management information system (MIS), which combines

process modelling, continual measurement and statistical analysis to identify situations requiring management attention. This tool offers the manager a powerful alternative to his traditional, and often unsuccessful, reliance on past experiences and historical reports to anticipate and avert problems. As Beer explains,

> Managers therefore guess the answers that can so easily be provided for them. It should not be too surprising that the guesses are so often wrong. At any rate, I have demonstrated by experiment that a probability-plus-computer monitoring system can detect a change in the movement of a performance index long before a human being can detect that change by eye in a graphical time series. (5:295)

Typically, MIS's provide historical information to the manager, often weeks or months after the fact. Use of such information either presumes that their has been no change since the last measurement, or that the current values are close enough that some heuristic can be used to extrapolate to the present. At best, the manager updates his information based on informal means (which brings into question the value of the report), yet still does not avoid some of the deficiencies inherent in traditional systems. The models with which the manager determines what he should control/monitor and what constitutes acceptable performance are usually in his mind, consisting of his point of view, theories of operations and management, and experience, and may be dictated arbitrarily based on requirements from higher levels of recursion (3:305-310). Such models are

"typically so simple that they can not go right" (3:311): they do not have the requisite variety to forecast the likely future events of interest to the manager (3:310). Clearly, accurate short-term forecasting, if available, would provide management with a better basis for current actions: to prepare for, or avoid, as expedient, probable future events in its operations and in its environment (8:346-349).

The significance of real time information can not be underestimated. By taking daily measurements of the variables and immediately comparing them statistically to recent past performance, any change can be detected the day it first occurs; well before any traditional management methods would notice a difference. Consequently, the manager is aware of an incipient instability and can take action to correct the situation and avoid undesired outcomes (5:500;8:348). Several steps are required to set up such a MIS.

The manager must decide what must be controlled in order to maintain stability. By developing quantified process flow models of each subsidiary viable system (operation) of SYSTEM ONE he can identify "major flows and ... process bottlenecks" (8:340), determine what elements of which must be controlled in order to maintain stability (8:340-341), and estimate the time the "manager would need to correct a damaging instability to one of the chosen

indicators" (8:350). A quantified process flow model, or quantified flow chart (QFC), would identify all important activities as boxes, each of which would be sized to indicate the volume or amount of product or effort, connected by lines, of relative thickness to the volume contained, indicating the pattern, from start to finish, of the process of each operational unit; Beer provides an example from his chilean experience (Figure 3) (2:253-254,273). In addition, a similar QFC of the environment of interest to SYSTEM FOUR must be developed and used together with the operations models (in the form of a single computer simulation model of the system in focus (3:313-320)) to "simulate alternative strategies for its own future, in different possible scenarios" (8:346). Beer proposes a model (Figure 4) of the two major types of corporate regulation, in the terms of the marketplace: to maintain earnings above some minimum level and to sustain the "match between product attributes and market demand" (2:186). To that end he isolates five control parameters: "product improvement (A), product innovation (B), ... potential operating efficiency (C) ... responsiveness (inertia) of the market (X), and ... the power to borrow money (Y)" (2:187) which management must control to maintain the firm's viability. In order to ensure this model reflects reality (as it changes over time), by avoiding a common fault of traditional models which is to

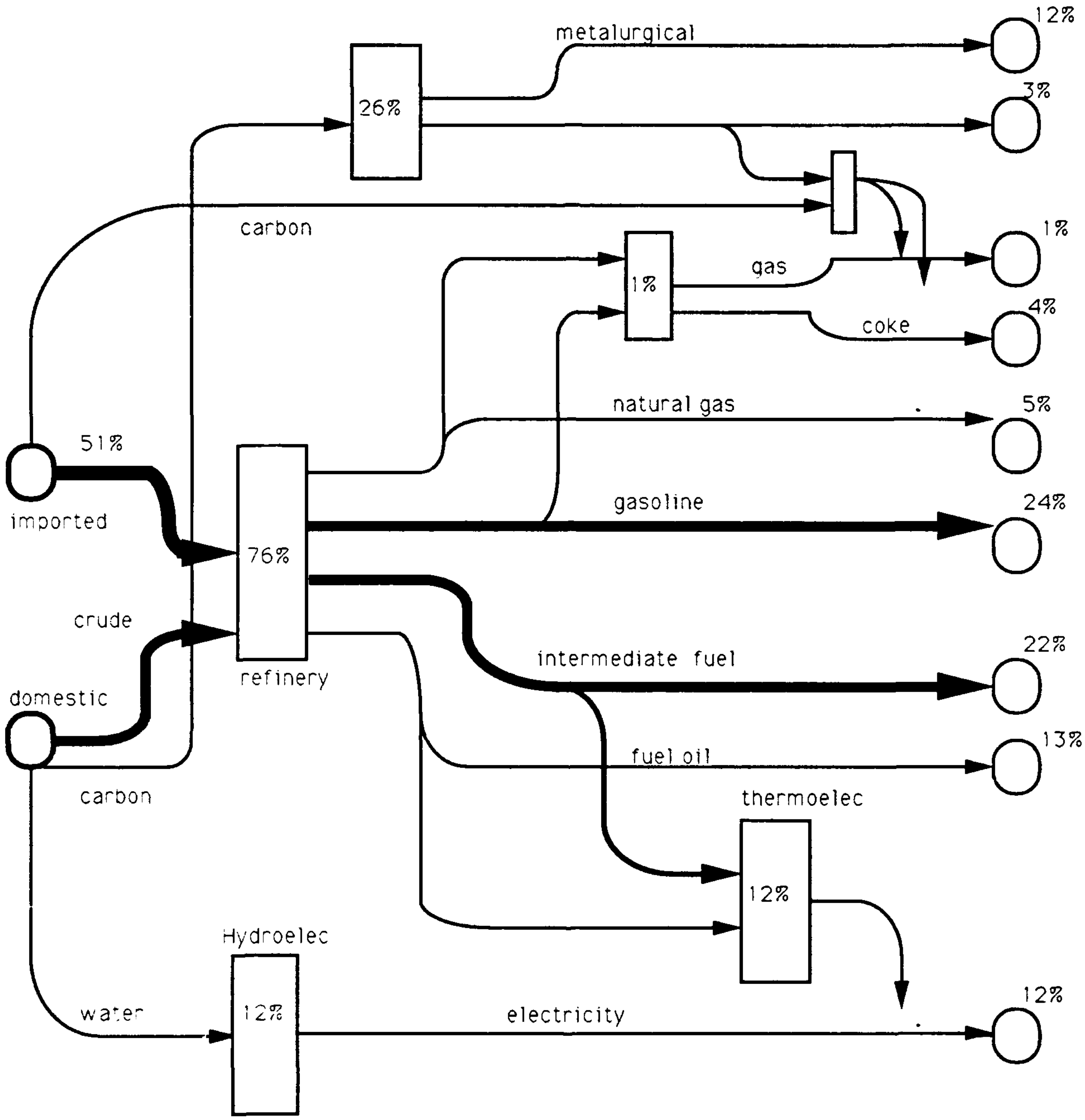


Figure 3. Quantified Flow Chart -- Chilean fuels (2:273)

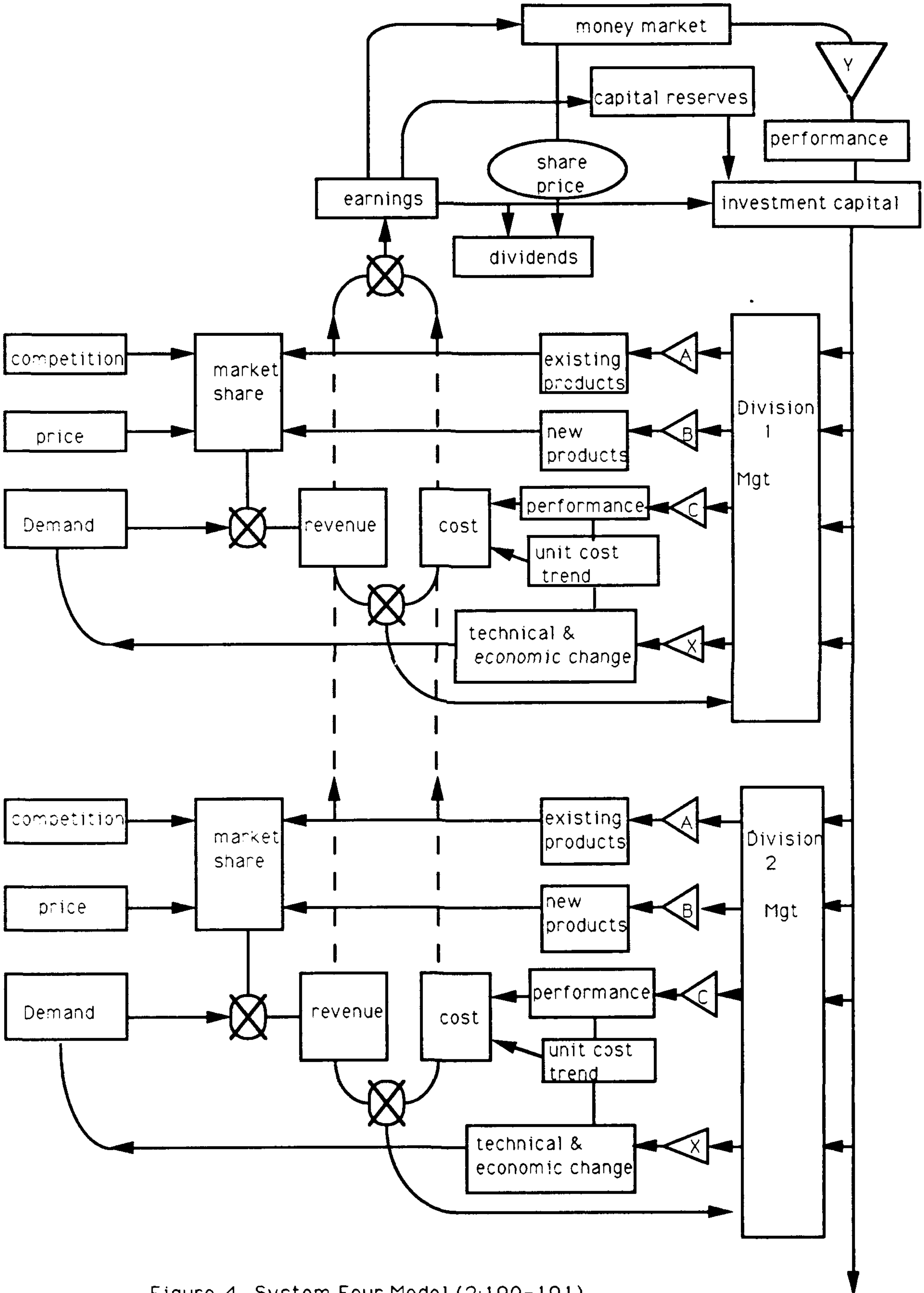


Figure 4. System Four Model (2:190-191)

assume static world conditions (3:309), the variable values predicted by the model are compared to real world events as they occur. This technique will be discussed later in the chapter.

The universal measure which management uses is money, not only because of its familiarity, but also because of its usefulness in comparing unlike organizations on common basis (profit, ROI). However, such measures provide an assessment of short-term viability but do not provide a means to "detect the mismanagement of latent resources" (2:162), which may well impact the long term viability of the firm. Beer recommends three measures of achievement which provide the same means of comparing unlike systems as a monetary measure, because they are ratios, but provide an added means of assessing the likely impact of current actions on future viability. These ratios are Measures of Achievement which are derived from the planning process.

Those elements which are essential to stability are the variables which define the state of the system at any one time. It is the manager's job to nominate values of three achievement levels for each variable, in keeping with experience and systemic purpose, required to assess stability: actuality (what is normally achieved), capability (what the system plans to achieve), and potentiality (what the system could achieve if changes were made). Each of these levels reflects a level of planning

within the organization -- a goal to which they are striving in the near, mid and far term, respectively. Each of these targets is compared by SYSTEM TWO as a ratio to that measured by the operation, creating an index between zero and one which indicates the stability of the situation, plan and normative expectation, respectively (5:293). The measure of actuality is obtained from SYSTEM ONE, the measure of capability is obtained from the SYSTEM FOUR model of the system-in-focus, and the measure of potentiality is obtained from simple simulation modelling (2:169). While all three levels must change over time and be tracked to assess plan stability, Beer focuses his discussion on the daily tracking of actuality and its use in managing system performance.

The three measures of achievement ratios are productivity (actuality/capability), latency (capability/potentiality), and performance (actuality/potentiality) for which the metasystem determines which mixtures of these ratios are likely to indicate incipient instability. Each day a measurement of actuality at each control point is tested statistically to determine the likelihood that it is a valid number. If so, the three measures of achievement are calculated. Each achievement index is tracked by SYSTEM TWO as a time series in the form of a statistical control chart of actual versus expected values. In addition, the indices are arranged

into "statistically homogeneous groups" (2:169). Each new index is compared to the calculated parameter value expected for a member of that statistical grouping. If the statistical tests indicate the index is a likely predictor of a relevant system change, the disparity is reported by the MIS, first to SYSTEM ONE, and, if it is not corrected within an anticipated time, then to the metasystem, for action (5:292-293). The mechanisms used in the MIS to assess the need for management to take action to avert instability will be discussed in more detail once the choice of variables is explored.

The question of what variables are necessary and sufficient to assure systemic stability is clearly a challenge worth additional consideration. Goldratt identifies three basic measures management needs to assess the state of the system; while his first applications related to the manufacturing floor to which the vocabulary is most familiar, he asserts that they can be applied to any organization (12:74): throughput, inventory, and operating expense. The first is an absolute measure of the rate at which the system provides output to the customer; the second is a relative measure of its current investment in resources, and the last is a measure of the cost of turning inventory into throughput (11:59-60). Seemingly, then, the manager could gain considerable insight into the system's current state by determining what constituted

these three measures for each subsidiary viable system of SYSTEM ONE of the system-in-focus and identifying the usual, planned, and potential values of each.

Both the maintenance of an accurate predictive model and the identification of incipient instability are achieved by statistical analysis of the measured variable values over time. Initially, actual measurements of each variable must be taken under all known conditions and converted to the three algedonic indices of interest. The indices must then be grouped using statistical Discriminant Analysis techniques to divide them into one or more statistical populations. Without pursuing a mathematical formulation of discriminant analysis, for which the reader is referred to a competent multivariate statistics book (ref: Applied Multivariate Statistical Analysis, Johnson & Wichern, Prentice Hall, 1988.), a conceptual description of the technique follows. Discriminant analysis is a type of regression analysis in which the groups of interest have qualitative values. Specifically, the task is to distinguish in which class an entity will belong, given the values of some of its quantitative attributes (5:293; 8:349; 15:357). For example, one may wish to determine between high and low risk projects. One must identify a number of variables (for instance: number of personnel, dollar value, amount of new design, etc) which appear to be related to the classification of interest. A matrix must

be developed of projects known to be of each class (ie high and low risk), with the values of each of the predictor variables. The mean and variance of each predictor variable in each class (ie high and low risk projects) is calculated. The assumption of discriminant analysis is that although the mean of each predictor is different for each class, the variance of each predictor and the correlation between each two predictors is the same in all classes (15:360). Discriminant functions are developed as weighted sums of the predictor variables. The weights of each variable in each function are chosen so that there is the least chance of misclassifying an entity (15:362). One less function is needed than classes in which one wishes to divide entities (15:368). The first is used to discriminate one class from all the rest; the next one more from the remaining, etc, until all classes have been distinguished. Once the discriminant functions are developed, they can be used to predict the class of a new entity, if that entity's attributes are known. The values of the predictor variables are used to calculate the value of each discriminant function. The values are then compared to the rules of classification. In the project risk example, there are only two classes and therefore one function; thus a rule might be if the value of the function is greater than 100, consider the project to be high risk (15:369).

Once the classification system is set up, daily measurements are made of the three values of each variable (8:346) and converted to the three indices, which are added to the evolving time series for each index. As world events change, the populations may change in mean value, value range, or additional populations may be differentiated (3:334). Bayesian probability theory is a form of short-term forecasting used to assess the likelihood that the value of each index indicates a chance variation or transient noise of little significance, or whether it is an indication of a slope or step change to the current performance of the index which the manager must respond (5:504; 8:349; 14). Bayesian probability theory asks the question: given the current index value, what is the probability that the current trend and slope of the index' time series are still correct (ie that they are not in the process of changing) (14). Its techniques inherently increase the sensitivity of the analysis as a change seems likely and update parameters based on accumulated data (14:353-357). If a change seems likely, the SYSTEM ONE manager is notified immediately of the indication of a potential incipient system instability (8:348).

Similarly, the model is kept up to date by comparing the values predicted by the model for a given event (combination of variable and attribute values) with that

real world event. Specifically, when a particular event happens, the values of the various predictor variables are input to the model and the resulting criterion variable values are compared with those measured for that event. The predicted and actual values are compared as a ratio with which future predictions about that event are made. For example, if a variable was predicted to have a value of 30 and it was measured as 60, the next time that value is to be predicted, whatever value the original model predicts is multiplied by 0.5 to provide the next prediction. Thus the model can learn and evolve (3:329-330; 8:349-350). Although such a system has been implement from scratch in a small plant in a six months time by competent statisticians and cyberneticians (3:337), Beer has marketed statistical software designed to conduct the necessary analysis, called "Cybersyn" (8:349-351) to minimize the statistical and computer programming expertise an organization must have to implement an MIS based on cybernetic principles.

III. Methodology

The methodology developed to conduct this research involved three basic steps. First, the literature of Goldratt, Beer, and their followers were studied in detail to develop a comprehensive understanding of their theories, and the means to apply them to an organization. Secondly, data about the SPO was gathered by conducting a series of telephone and in-person interviews and by reviewing SPO documentation concerning the DSCS program. Subsequently, a preliminary application of the theory to the workings of the DSCS SPO was conducted, following the procedures suggested by Beer, Espejo and others regarding their study of numerous organizations, ranging from small businesses to entire countries, in Europe and the Americas (V:35-37), including the Canadian Marine and Fisheries Administration (D:15), the social economy of Chile (B:245-347), and an international insurance company (V:215-270).

Data Gathering

Specifically, once the theory was sufficiently understood -- after months of reading and re-reading and diagramming the texts -- a series of free form questions were developed to solicit information needed from the SPO to apply the theory. The questions included:

1. What is your job in the SPO?
2. With whom do you interface to complete your job? How

well do you work with these people? How helpful are they to you in completing your tasks? What are their jobs?

3. What steps do you follow to complete each task (process)?

4.. What are the biggest frustrations (bottlenecks) for you in getting the job done?

5. What is your working environment like?

6. How much direction (freedom) do you have in conducting your tasks? Who provides direction? How often? When do you need approval before you take action?

&. How does your function fit into the whole SPO organization?

Specific questions were formulated after an initial background was obtained to fill in information gaps identified as the author applied the theory to the SPO. Examples of such specific questions include:

1. What does the AFPRO do for you? Does an agreement between your organizations exist? How often do you talk with them or ask for their help?

2. How is the GE DSCS Flight Segment Division structured? Does GE treat DSCS and IABS as a single effort? How well are they performing on the contract? How quickly do they surface problems?

As data was gathered, a step by step application of the theory, as documented in the literature review, was conducted, additional needs for information were

identified, and additional data was gathered. This iterative approach provided the opportunity to assimilate information about the SPO relevant to the research, precluding the need for a detailed assessment of information needs at the outset of the inquiry.

Diagnosis

The organization was first diagnosed for viability, using the data concerning the SPO and the author's understanding of the acquisition process. Feedback was solicited from SPO members concerning the cybernetic functions of various SPO tasks.

Although the process of applying the VSM to any particular organization is a detailed and creative task requiring both an understanding of cybernetics and thorough knowledge of the organization under study (8:338), Beer has suggested a generic procedure to follow (4). In general, one must map the people, policies, procedures, and functions which comprise the five subsystems of the organization of interest onto the VSM, and identify the current interactions of each with every other, with adjacent levels of recursion, and with the environment.

Specifically, the diagnostic process may be summarized in six steps. Throughout the analysis, one must recall that "many activities of the actual firm will be found to be playing a variety of roles in terms of the viable system" (2:155-156). First, a system-in-focus was chosen,

and its boundaries with the environment and with the next higher and lower levels of recursion specified. Beer notes that "a model is neither true nor false: it is more or less useful" (4:2), indicating that the choice of system is not obvious or set but depends instead on the purpose of the modelling effort. However, caution was used in defining the system so that only one dimension of the system was considered in any one model. Once the system was defined, its operational units and those of the next lower and higher level of recursion were identified. (4:2-3) Next, the variety amplifiers and attenuators operating on the two (horizontal) homeostatic loops between each operational unit and its management and its environment were assessed for adherence to the law of requisite variety and the first principle of organization (4:32). To complete an initial assessment of SYSTEM ONE, the means by which each operational management regulates its operations and the connections between the organizational units were identified, and the commonalities of their environments and the adequacy of the horizontal communication channels and their transducers in light of the principles of organization were assessed (4:41-56).

Secondly, the mechanisms of SYSTEM ONE oscillations and the means by which they are damped, which constitute SYSTEM TWO, were identified, and the ability of SYSTEM TWO to maintain stability and its perception as a service or

requirement were assessed (D:68-76). SYSTEM TWO conducts all performance routine measurements for the system-in-focus and identifies signs of incipient stability to SYSTEM ONE, and in some cases to SYSTEM THREE as well.

Thirdly, the functions and people which comprise SYSTEM THREE (including SYSTEM THREE STAR and those responsible for SYSTEM TWO), and the legal and corporate requirements, the resource bargain, and the means of accountability between SYSTEM ONE management and the management of the system-in-focus were discerned (4:41). An assessment of the autonomy and cohesion of the system, the adequacy of the homeostatic loops, and the comparative strengths of SYSTEM THREE's command and non-command activities was then made.

Fourth, all SYSTEM FOUR activities, which Espejo suggests equates to intelligence-gathering in its broadest sense (8:84-89), studying the external environment for insights to incorporate into the planning process as Beer defines it: "a continuing process leading to the commitment of resources now, that the future may be different" (4:100), were noted, being careful to include only activities of the system-in-focus. Assessment of the adequacy of the homeostat between SYSTEMs THREE and FOUR was carefully conducted, since Beer flatly states that "very few enterprises have a well functioning SYSTEM FOUR and even

fewer conform to the principles which govern homeostasis" (4:117).

Fifth, SYSTEM FIVE was identified and his means and ability to provide closure to the system-in-focus was considered. Also, an assessment of SYSTEM ONE's ability to alert SYSTEM FIVE directly of a problem, and consideration of the adequacy, formality, and automation of this algedonic signal was made.

Finally, the requisite variety of each of the links between the five subsystems at the adjacent levels of recursion was assessed for compliance with the Law of Cohesion (4:132).

Prescription

Once the preliminary diagnosis was made, prescriptions for improvement were considered and discussed with the SPO. Prescription focuses on any functions or interactions which do not comply with the structure of the VSM, the principles of organization, and the axioms of management. Such functions and interactions are diagnosed as cybernetic pathologies which can be corrected by bringing them in line with management cybernetic theory (4:xiii). Since cybernetics describes what is of necessity happening in any organization, the operative question is how to improve the evolved system through recognition of the current mechanisms and conscious redesign of the formal or sanctioned structure to match (or better) the existing

actual structure. As Beer explains, "the value of the model is to make clear how the organization actually works as distinct from the way it allegedly works, so that it may be streamlined and made more effective" (2:155).

Quantified Flow Charting

Once the structure of the organization was diagnosed and prescribed, a preliminary consideration of process modelling was made. To develop a preliminary QFC, the time-sequenced flow of paperwork necessary to conduct the process of contract modification was obtained through discussions and diagrammed with SPO personnel. Every agency acting on each of the various documents required to request, evaluate, negotiate, and award a contract was identified as a box. The thickness of the lines connecting the boxes was used to indicate the extensiveness of the task for the agency from which the line proceeds. Once the QFC was complete, apparent bottlenecks were identified.

Measurement and Analysis Tools

Lastly, creative consideration was given to cybernetically valid measures and measurement points within the contract modification process, using the QFC for guidance, and recommendations for the rudimentary design of a measurement and analysis tool were made. Potential measuring points were identified, corresponding to critical or bottleneck points in the process, from which to assess

the performance of SYSTEM ONE and of the SPO itself. At each measurement point, one or more critical measures of performance were suggested, using Goldratt's three necessary and sufficient measures of performance: throughput, inventory and operating expense, as a guide.

IV. Analysis and Findings

Introduction

Analysis of the data gathered regarding the Defense Satellite Communications System (DSCS) portion of the Satellite Communications (SATCOM) Program Office (SPO), from a sequence of interviews with SPO personnel and review of SPO documentation (Appendix B), will include a preliminary diagnosis of the SPO organization and functions using the VSM and a quantified flow chart of the contract modification process. The reader is reminded that much of the analysis discusses situations with which every SPO is faced and that the SATCOM SPO is offered as a convenient vehicle with which to address these issues in a specific, rather than a general, manner. The findings will include a prescription of means to better SPO organization which result from the cybernetic analysis and a rudimentary design of cybernetic measurement and analysis tools. Except where noted, data concerning SPO operations were gained in an iterative manner throughout the data collection process and can not be directly attributed to a unique source.

Background

The SATCOM SPO of Space Systems Division (SSD) of Air Force Systems Command (AFSC) has been in existence for over 25 years; however, personnel and projects have changed continually since its inception. Although the SPO

currently manages several satellite efforts, the one major program, and the one on which this analysis will focus is the DSCS Program. The third generation of DSCS satellites (DSCS III) has almost completed production; a total of ten DSCS III satellites remain unlaunched -- three remain in production while the remainder are currently in storage awaiting modification, test and launch over the next several years (7:6,18). An Integrated Apogee Boost Subsystem (IABS) is in concurrent development and production to provide the launch vehicle, the Atlas II rocket, sufficient power to place the satellite in geosynchronous orbit, in preparation for the first such launch in 1991. In addition, plans are in development for follow on efforts, either to develop a new generation of DSCS or to modify some of the existing satellites further to fulfill as yet unmet needs of the users (13). The SPO consists of about 60 people, in five functional divisions: program management, engineering, integration and operations, program control, and contracts (Figure 5).

Diagnosis

Definition of Systemic Boundaries and Purpose. The chosen system-in-focus is the DSCS SPO (amplified by AFPRO-GE, Aerospace and Techolote Corporations support) metasystem (SYSTEMs TWO through FIVE) and two subsidiary viable systems (SYSTEM ONE & lower level of recursion), the satellite and the IABS efforts at the defense contractor's

SATELLITE COMMUNICATIONS PROGRAM OFFICE

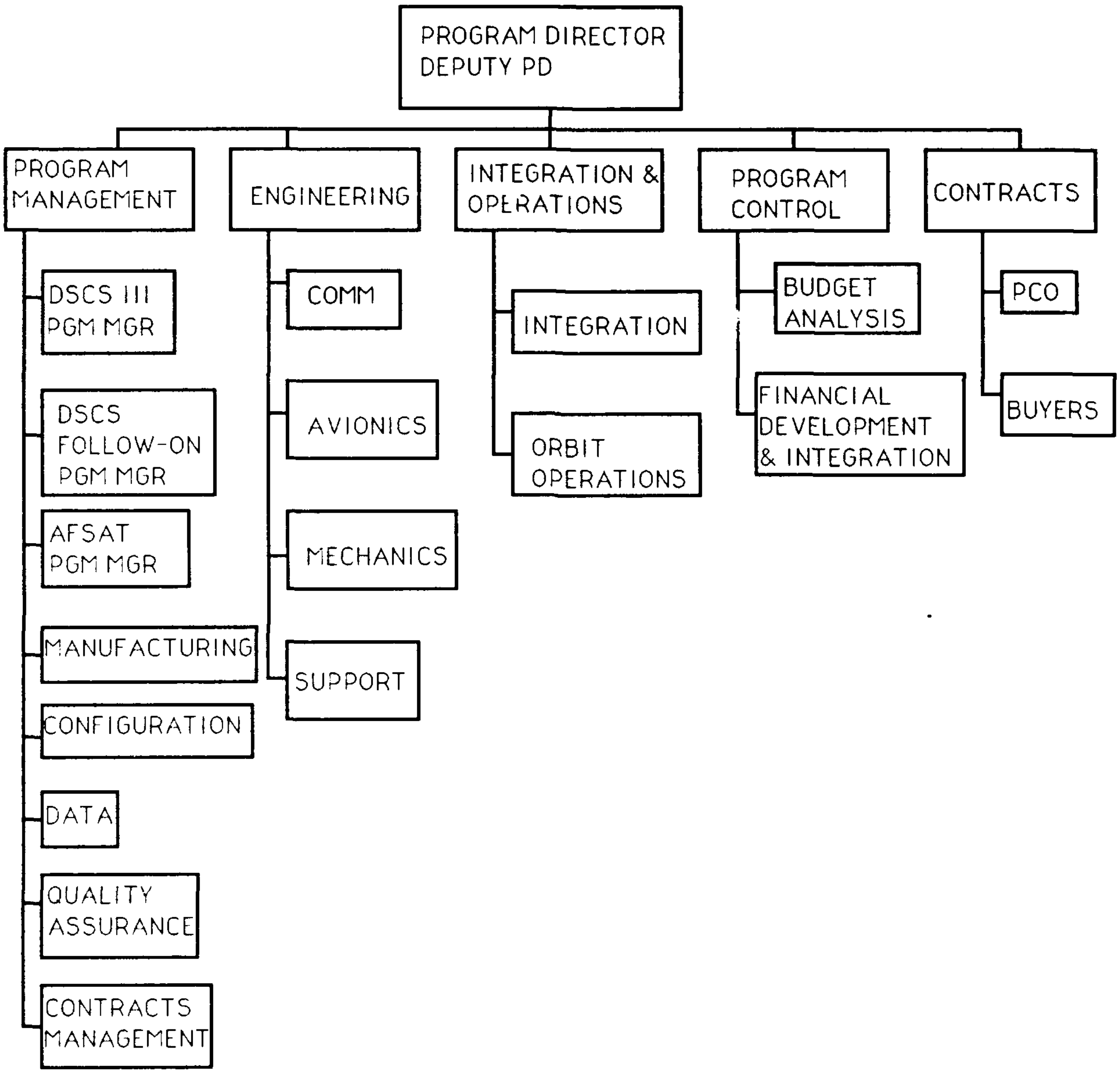


Figure 5. SATCOM SPO Organizational Chart, as of 31 JAN 90 (17)

facilities, General Electric, Valley Forge, Pennsylvania. The subsuming level of recursion (of which the system-in-focus is one the subsidiary viable systems of its SYSTEM ONE) is defined along the recursive dimension of acquisition as the Space Systems Program Executive Officer (PEO) by Congressional law. The SPO Program Director reports to the PEO (a Brigadier General) who provides senior level guidance to the program (as well as four other major space programs) and who reports directly to the Assistant Secretary of Defense for Acquisition. However, since the PEO's tasks are only acquisition related, another system must be combined with the PEO structure to define the next higher level of recursion. AFSC (including SSD senior management) is a part of the metasystem, providing personnel and financial resources via the Programming, Planning and Budgeting cycle (PPBS) to accomplish the acquisition and direction via regulations applicable to all members of AFSC (Figure 6).

The declared purpose of the system-in-focus is to develop, test, produce and deploy DSCS satellites. The declared purpose of the PEO is the develop, test, produce, and field space systems, and the declared purpose of AFSC is to man, train, and equip the SPO. In effect, this situation of two interwoven chains of command greatly increases the variety which the SPO must handle, because the AFSC and PEO structures are distinct, but overlapping in

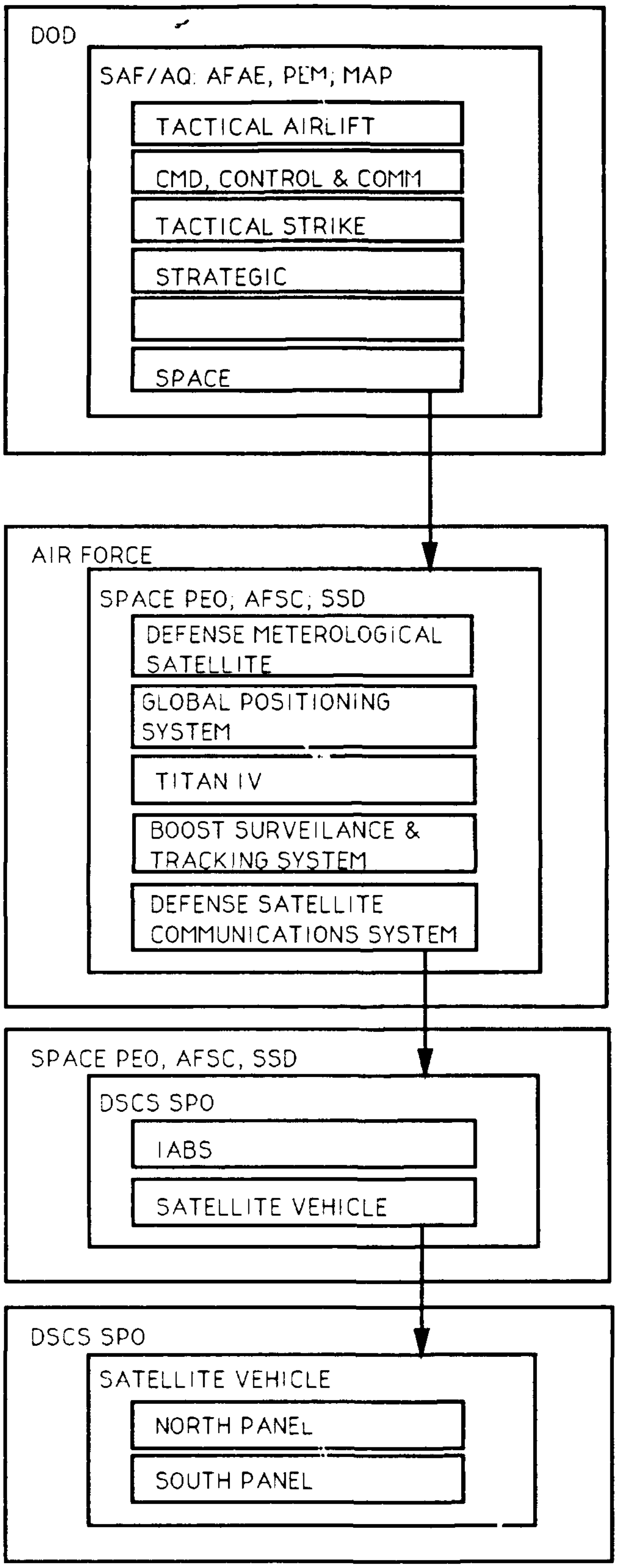


Figure 6. DSCS Acquisition Recursion Dimension

responsibilities, and may provide conflicting information, direction, or feedback to the SPO along any of the vertical communication channels. It should be noted that the GE operations of interest are also part of a corporate recursive dimension (Figure 7) whose declared purpose is to make money. Consequently, SYSTEM ONE must respond simultaneously to two metasystems (SPO and corporate), just as the SPO must respond to both the PEO and the divisional command structures.

SYSTEM ONE. The producing units of the system-in-focus have been identified as the DSCS satellite and IABS efforts at GE. Both of these efforts are a part of the GE DSCS Flight Segment Division. Consequently, while separate activities, facilities and workers preclude consideration of the two subsidiary viable systems as a single entity, they share upper management, which increases the possibility of oscillations caused by competition over divisional resources, but simultaneously increases the likelihood that such conflicts will be damped by common policies, rich information exchange and a common purpose. Indeed, the commonality of senior personnel appears to have far more advantages than disadvantages for the SPO by lessening the communication burden between contractor and SPO (seemingly half of that required if two contractors were involved).

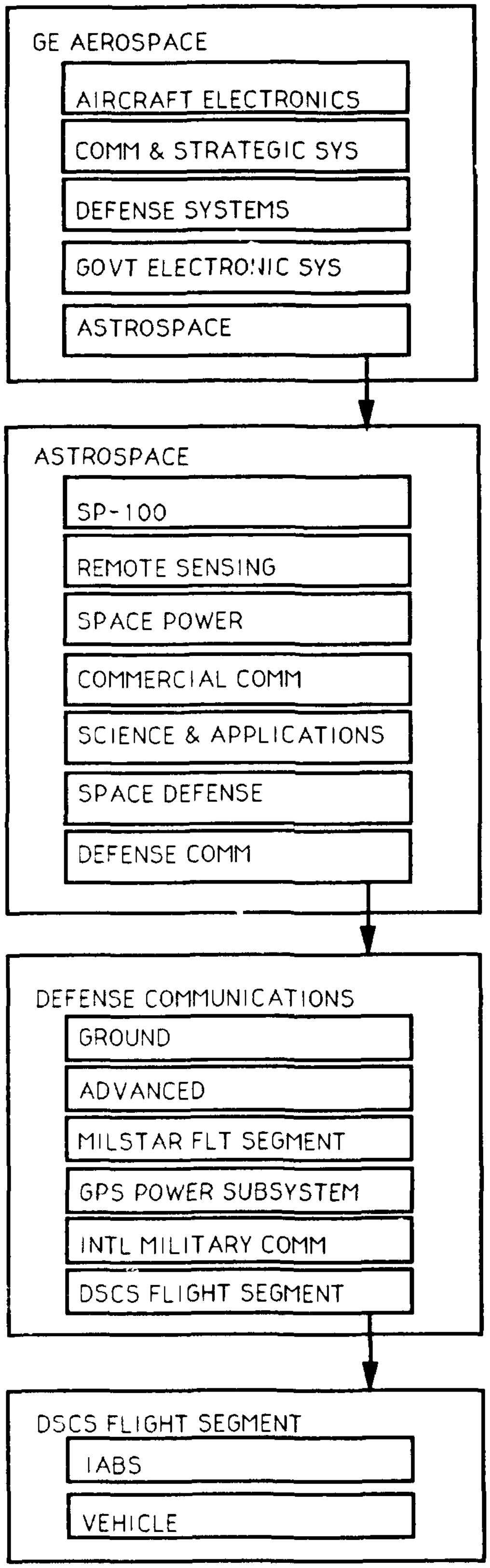


Figure 7. GE Corporate Recursion Dimension ("DSCS III Program Orientation" unpublished briefing, 1988)

Within the DSCS Flight Segment Division are three subsidiary viable systems (two levels of recursion from the system-in-focus): IABS, which has not yet been subdivided (but may be as development progresses), the North Panel ("brains" of the satellite), and the South Panel (attitude controls of the satellite). An evaluation of the viable subsystems making up SYSTEM ONE of the system-in-focus would require a detailed analysis of the contractor's management-operations functions and interactions which was not a portion of the author's data collection and is left to the SPO to perform as appropriate in cooperation with GE.

The system-in-focus is one of five major programs within the AF Space Programs acquisition recursion level. In its role as a subsidiary viable system within SYSTEM ONE of the Space Programs recursion, the system-in-focus consists of a management unit comprised of SPO and support personnel, an operations unit consisting of GE DSCS Flight Segment activities and personnel, each with a relevant environment (Figure 8). Thus, the system-in-focus will first be analyzed as the interaction of three units; in later sections, the management and its interactions with its SYSTEM ONE will be expanded.

From the point of view of the chosen dimension, the immediate environment of the operations unit includes its suppliers, other GE divisions, corporate GE (embodied in

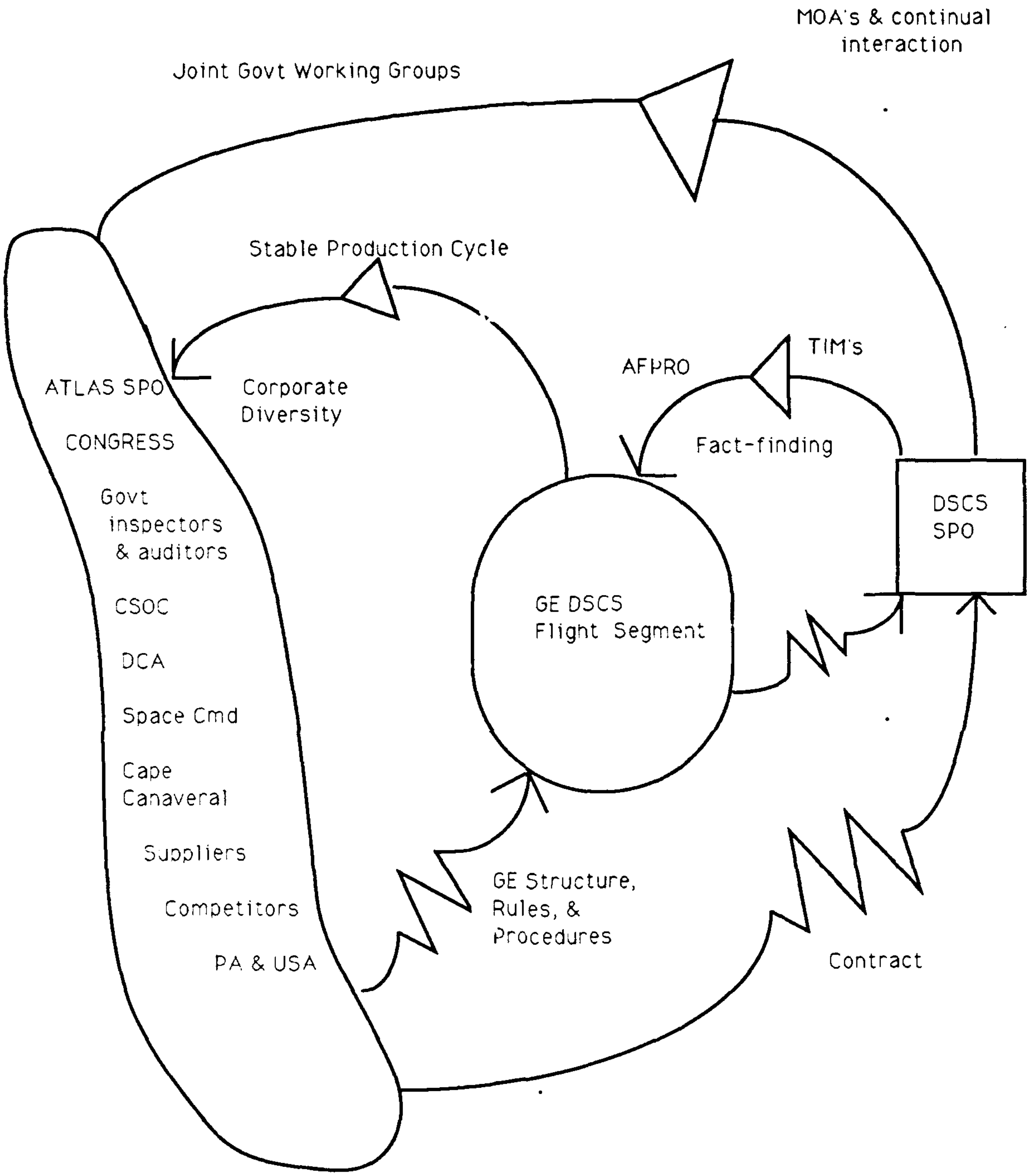


Figure 8. Systemic View of DSCS SPO

policies, procedures, regulations, and expectations), competitors, Valley Forge, Philadelphia, Pennsylvania, Mid-Atlantic and the United States (indicated by laws, economics, and/or public opinion and policy) and CSOC [(government agency which monitors and controls the operational satellites) with whom they work to maintain optimal utility of orbiting satellites and identify improvements to be considered for unlaunched satellites]. The environment of the SPO includes the Defense Communications Agency (DCA) [the system manager, who levies transmission, traffic load, and other communications requirements in order to attain compatibility of DSCS users and the space segment], the Atlas SPO [to ensure proper interface of the satellite and IABS with the rocket and rocket availability to support scheduled launches], Cape Canaveral [to integrate schedules and configuration requirements of the launch pad, and processing facilities where the satellite and IABS are joined to the Atlas II and fueled for launch], Space Command and many other government agencies outside the recursion dimension to the extent that they interact directly with the SPO, such as Congress, AFSC and DOD inspector general and auditor agencies, and the political and economic environment at large.

While variety attenuation and amplification between GE and its environment can be discussed in only general terms by the author, the variety amplification and attenuation

mechanisms between the SPO and the contractor and the SPO and its environment will be described in greater detail. GE may be able to amplify its variety with CSOC and SPO engineering and operations because of its close working relationship which should allow GE to anticipate and shape many of the changes, rather than simply having to react to unexpected Requests for Proposal (RFPs). In addition, its long term contractual arrangements with the SPO may provide a stability which amplifies the contractor's ability to manage its suppliers and balance its needs with those of the other GE divisions because it is in a better position to plan ahead. As well, GE is a diverse corporation which enhances its own stability in a worsening economy; the corporation as a whole should be able to protect its more volatile parts through many economic changes. Its structure, including corporate and divisional rules and procedures regarding personnel and operations, attenuates the variety of the environment with which the operations must deal. SPO members in concert with GE management must make the assessment of an adequate variety balance, which the author can only guess is relatively stable.

Amplification of SPO variety to match that from other government agencies in its environment is facilitated through joint meetings with DCA and Space Command (who represents all the DSCS users to the SPO), interface meetings and continual conversations between the Atlas and

DSCS SPOs, and frequent conversations and meetings with the 6555th Aerospace Test Group at Cape Canaveral. The SPO's relationship to its environment will be discussed in more detail within SYSTEM FOUR.

The comprehensive attenuation device between the SPO and the operations unit is the contract, including all modifications, which defines the outcomes, many of the means to attain them [via Federal Acquisition Regulation (FAR) clauses, the Statement of Work (SOW), the technical specifications to which the products must adhere], and the means by which plans, procedures, progress and performance are to be reported to the government [via the contract data requirements list (CDRL)]. SPO amplification devices include monthly technical interchange meetings (TIMs) with GE, weekly telephone conversations between SPO and contractor engineers, government "fact finding" prior to contract modification negotiations, review of GE's program directive [internal tasking to reply to a government request for proposal] to ensure GE is preparing an acceptable proposal, contractual availability of an award fee with which the SPO can incentivize desired contractor performance. Although the contract as a written document does not possess requisite variety to ensure desired results, in concert with the less formal amplifiers outlined above built on the basis of mutual cooperation and interest, it appears that the variety balance between SPO

and the contractor is generally stable, accepting for now the current laws and policies which will be discussed within SYSTEM THREE. The one counterexample noticed during the data gathering process was in regard to the ongoing contractual efforts for IABS production, negotiations were held up for some time while large disparities between SPO and contractor estimates of the effort required were investigated. No clear and agreed to channel for this investigation existed between the contractor and the SPO, seemingly limiting the ability of the SPO to resolve this situation quickly and appropriately.

While it seems clear that variety balance among the SPO, GE, and their environment is maintained with less pain than in many organizations due to their relatively stable (long-standing) relationship and open communication, the amplifiers and attenuators by which this arrangement is maintained were not designed, and therefore may not be adequate to handle less stable conditions. such as those of negotiating the significant work of the IABS. The current situation puts great emphasis on parallel formal reports amplified by a great deal of informal communications, taking up a great deal of participants' time and energy.

Because most of the formal, written, least useful (because they are outdated and must be updated informally and continually to provide adequate information for management decision-making) are required by regulation

or policy at higher levels of recursion, the SPO is restricted in its extent of redesign of its means of communications with the contractor and environment, unless it can strike a new bargain with the PEO and/or AFSC to limit the legal and corporate requirements with which it must comply. That not withstanding, the current burden in terms of cost, time and stress required to gather and distribute the volumes of information currently demanded is very large; seemingly a more timely, efficient and effective information system could be developed to provide a better means for decision-making and to free both SPO and GE personnel to more ably fulfill their other tasks.

SYSTEM TWO. The oscillations which are monitored by the SPO include SYSTEM ONE's cost, schedule, and technical performance and the SPO's own performance. Performance is assessed by comparing actual with expected values, on a monthly basis in most cases, but in a few cases as seldom as once a year. SYSTEM TWO functions are variously performed by SPO engineering, integration, program control, contracts and program management personnel, and Techolote Research Corporation.

Cost and schedule performance is assessed by program control personnel in conjunction with the program manager using the monthly Cost Schedule Control System Criteria (C/SCSC) Report provided under the contract by GE to the SPO. This report, received approximately four weeks after

the month it describes, provides a detailed discussion of the causes of all variances between actual and contractually required cost and schedule. Program control reviews the document in detail, requests comments from SPO engineering and program management personnel -- in effect bringing the report up to date by providing information they have acquired by other, less formal, means -- discusses issues with GE, and reports monthly to the program director. The SPO uses the award fee, in part, to motivate good contractor cost and schedule performance; however it may be little incentive, since most contracted actions are tied to the launch schedule for which the government is responsible, any delay is cause for negotiation, which can alter the expected cost and schedule (realign it with actuality).

Additional SYSTEM ONE scheduling information is gathered from SPO members by Techolote each month from which they update a data base and produce a very detailed report of the integrated schedules required for each satellite to prepare it for launch. Techolote and GE have an adversarial relationship, so any confirmation of the information in Techolote's reports is done informally by SPO members, rather than by Techolote as part of its data gathering process. Schedule drivers are identified and action taken by SPO personnel to minimize any impacts of schedule delays.

Engineering, integration, and operations SPO personnel focus on technical performance. Engineers make weekly phone calls, attend monthly Technical Interchange Meetings (TIMs), review test reports, and may participate in the testing process (or at least remain informed by on-site AFPRO observers), to identify discrepancies and identify means to resolve them which meet AF, as well as GE, needs and requirements. One area of major concern is what the impact of any change will have on the weight, balance, and interfaces of the satellite. Integration personnel ensure that any change to the satellite can be accommodated by the Atlas II and the Cape Canaveral facilities. The operations division monitors the operation of satellites in orbit: performance discrepancies are identified and solutions to prevent similar occurrences in new satellites are considered.

Additional routine SPO means of monitoring SYSTEM ONE performance include bi-monthly program reviews, and AFPRO representatives who work with GE to resolve engineering problems, attend GE meetings, and conduct inspections and verifications on behalf of the SPO.

Because a single GE division is responsible for both subsystems of SYSTEM ONE, GE undoubtedly conducts much of the necessary SYSTEM TWO function by coordinating internal schedules, priorities, and manpower and other resources, between the two subsystems, because it is

probably in GE's best interest to have both functioning as stably as possible, rather than competing with each other. To the extent that the GE corporate recursion dimension profits from favoring one subsystem GE will work against the SPO, otherwise they will likely work together to ensure stability.

In general, the more open communication among the participants, the more likely the SYSTEM TWO mechanisms will be able to identify and correct instabilities; however, the time lag involved in the current formal and structured measurements of performance hamper the manager's ability to avoid problems; on the other hand, the more timely and less formal mechanisms provide a far less structured data gathering activity in which important data can be missed simply because the topic or situation was never discussed. Ideally, one would like to provide a more forward-looking management tool: a more timely, but still very structured, vehicle by which to measure critical variables of contractor (and internal SPO) performance. In addition, it would benefit all participants if GE were convinced that SYSTEM TWO scheduling and performance tracking devices were indeed provided as a service, rather than simply a meddlesome requirement of the government. The increased cooperation gained by such an understanding could greatly improve the overall performance of the system-in-focus. For example, the probability of accuracy

within the Techolote schedule tracking report would be greatly improved if GE provided direct input; however, because the involvement of an outside contractor is considered perhaps an indication of a lack of trust in GE's internal scheduling, or at least an indication of government micromanagement, GE provides information in an unstructured manner through conversations with various members of the SPO in the course of normal business. To the extent that GE's internal plans and the Techolote report differ, the complex scheduling integration task is indeed an incipient instability which could likely be disastrous for the SPO.

SPO performance is monitored in a number of ways -- many informal and at least three which are formal. The rate of obligation of funds is tracked by program control for reporting to the SSD comptroller and the SPO Director. In addition, contracting officers and buyers report their number of completed contracting actions to the SSD functional contracting office. Further, the SPO Director receives a bi-monthly briefing ("BEAR") of the program, during which he undoubtedly assesses the performance of the SPO and its members. Less formal means include the continual appraisals (readily shared to the author) of coworkers by each other, which may of may not be passed along to supervisors, who may or may not take action to

correct (praise) any behavior which is adversely (positively) affecting SPO performance.

SYSTEM THREE. The day-to-day management of SYSTEM ONE involves the SPO program management, contracting, integration and engineering personnel as well as GE divisional management. The legal and corporate requirements are embodied in the federal statutes, Federal Acquisition Regulations (FAR), DoD directives, and Air Force, AFSC, and SSD regulations and policies which are applicable to the DSCS program and delineated by law and/or in the DSCS contract between GE and the government. The contract itself is the resource bargain between the contractor and the government in that it specified what GE is to do (Statement of Work) and what resources (money) will be provided to accomplish the agreed-to program.

Theoretically, the contractor is fully accountable for completion of the program according to the legal and corporate requirements and the resource bargain. Since the current contracts are "firm fixed price", the contractor is responsible for providing the contracted end items at that price, regardless of what the final costs are. In addition, the end-items must pass tests designed to prove they meet all technical requirements before the government accepts them, and the government must be compensated for any contractor caused schedule delays. However, in practice, the contractor has many legal avenues of negotiation which

softens this accountability. Schedule delays are seldom one-sided, costs are subject to renegotiation every time the contract is modified, and test procedures and contracts are often less than perfect. Consequently, the practicable accountability is a function of the working relationship between the SPO and the contractor. To the extent that knowledgeable people in government ask sufficient pointed questions, well informed GE officials respond with thoughtful, thorough responses, anticipate and discuss any necessary unasked queries, and both parties fully comply with the intended punishments and rewards specified as a part of the legal and corporate requirements, GE accountability may be sufficient.

The autonomy of SYSTEM ONE is drastically limited by government regulations and procedures for not only what tasks GE is to perform, but how they are to be conducted as well. In addition, continual direction, clarification, and changes steer the course of SYSTEM ONE. Therefore, cohesion is very strong; indeed SYSTEM ONE must be very responsive to the metasystem, on which is has become dependent out of inherent necessity: the metasystem, rather than an independent marketplace, determines the acceptability of SYSTEM ONE conduct and performance. Most all the metasystemic control is conducted on the command access; since even SYSTEM TWO activities are perceived as requirements, and SYSTEM THREE STAR is used sparingly.

The SYSTEM THREE STAR ad hoc audit function would ideally consist of unscheduled plant-floor visits and meetings with management personnel to make an independent assessment of the real status of the program. This is virtually unheard of in the defense industry because all visits must be announced to allow security access and contractor personnel availability. To the extent that GE does not shelter SPO personnel from various people or activities during scheduled visits (TIM's, Program Reviews) and fully answers the well researched questions of the attending SPO cadre, additional information can indeed be gained. In addition, to the extent that AFPRO personnel make ad hoc inquiries, on their own or in response to SPO questions, and report their findings to the SPO, a more complete picture of SYSTEM ONE performance can be obtained.

In turn, the system-in-focus, as a productive unit of the next higher level of recursion, performs under the legal and corporate requirements of SSD, AFSC, AF, and DOD regulations, under the resource bargain of the Program Management Directive (PMD) agreed to in the approved Baseline for DSCS, and for which the program director is accountable to the PEO. SSD functional staffs, AFSC Inspector General (IG) teams, and ad hoc inquiries from the PEO and his staff constitute the expected THREE STAR activities of the next higher level of recursion in relation to the SPO. The SPO appears to have little more

autonomy than GE, since it is governed as well by a host of regulations and policies of SSD, the PEO and AFSC, and higher management levels. For example, any significant contracting action requires the review and approval of numerous outside agencies. Because of the matrix nature of SSD and the continual involvement of many outside agencies, cohesion between the SPO and the next higher level of recursion is high, again mostly communicated via the command channel. Within the government most everything is tasked as a requirement, with repercussions for non-compliance, therefore SYSTEMs TWO and THREE STAR functions are consistently perceived by both the higher level of recursion and the SPO as command channel activities.

SYSTEM FOUR. Primarily, engineering and program management personnel query the environment and consider alternative futures for the DSCS program. The program managers are in contact with DCA and Space Command to understand future requirements, short- and long-term, and discuss alternative means to meet them with engineering and operations personnel. Of current consideration for the long-term are (1) a concept called "Normalization Space" initiated by Space Command who is looking to have satellite systems turned over to them, just like other systems are turned over to a using command -- currently space systems are not "normal" in that they are "owned" by systems

command for life -- and (2) how to meet the wide band transmission needs of DSCS users under predicted threat scenarios in the next generation of DSCS satellites, and whether that new generation will be a new start program or a modification of existing DSCS III satellites. In the short term, are actions to implement identified modifications to the DSCS III satellites and to ready the satellites for launch, including test, transportation, integration, and fueling. Of concern are EPA's direction to build a new processing facility at the Cape and the existence of new fueling safety concerns.

The balance between SYSTEMs THREE and FOUR appears reasonable in the long term. The engineering and program management staff are actively and iteratively involved in both the present day-to-day and future planning. The focus in more in the present than the future, because much of the future will be dictated by DCA, Space Command, the higher levels of recursion, and ultimately Congress. However, to the extent that alternative futures are being considered and fully communicated to those who will define DSCS' future so that the most informed decisions can be made, the SPO is performing well.

However, in the short term, it appears planning is most often incomplete, based on incomplete information, or reactive (vice proactive) in nature -- SYSTEM THREE has overwhelmed SYSTEM FOUR in this arena. Of much concern to

SPO members was the current lack of coordinated planning and scheduling of contract modification activities within the SPO, especially among the contracts, contract management, and program control divisions. The contracts personnel felt that things were continually done in a last minute fashion. Program control indicated that they were usually not consulted concerning a modification effort until the effort was well under way and the proposal was about to be received. A case in point was recounted in which the strategy included use of funds which could not be used for that purpose; by the time program control was consulted and the error was discovered much of the preparatory work of the SPO and the contractor was complete and had to be reaccomplished (17). It is apparent as well that there is a disparity between the expectations of the program management division and the actual performance of the contracts division (17), resulting in routine division level scheduling and priority discussions and an antagonistic and instable work environment for those involved in the contracting process.

SYSTEM FIVE. The policy setter for the SPO is the program director. His vision for the SPO is set out as a list of publicly displayed objectives (Table 4) and experienced by every SPO member at meetings, briefings, and during informal office visits of the director.

Table 4

SATCOM SPO Program Objectives (17)

1.	Maintain Capabilities of On Orbit Constellations
2.	Launch Replenishment Satellites ASAP
3.	Build Quality Hardware/Software on Time & Under Budget
4.	Improve Systems Ability to Survive and Operate Across the Spectrum of Conflict
5.	Develop Follow-on System to Satisfy Future Requirements and Survive the Threat

To the extent that his five division chiefs recognize and support his initiatives, they will reinforce and be perceived as part of SYSTEM FIVE by the SPO workers. SYSTEM FIVE and GE are in direct contact at least weekly; however, whether this is adequate to provide necessary and immediate algedonic signaling is largely dependent on the openness of GE management -- their willingness to discuss concerns frankly as soon as they come up -- to solicit the interest, help, support, and guidance, as necessary, of the SPO.

The mapping of the SPO onto the VSM is summarized in Figure 9.

Quantified Flow Chart

The DSCS SPO contract modification process is a complex and time consuming one which involves most all SPO personnel. To make a preliminary assessment of the

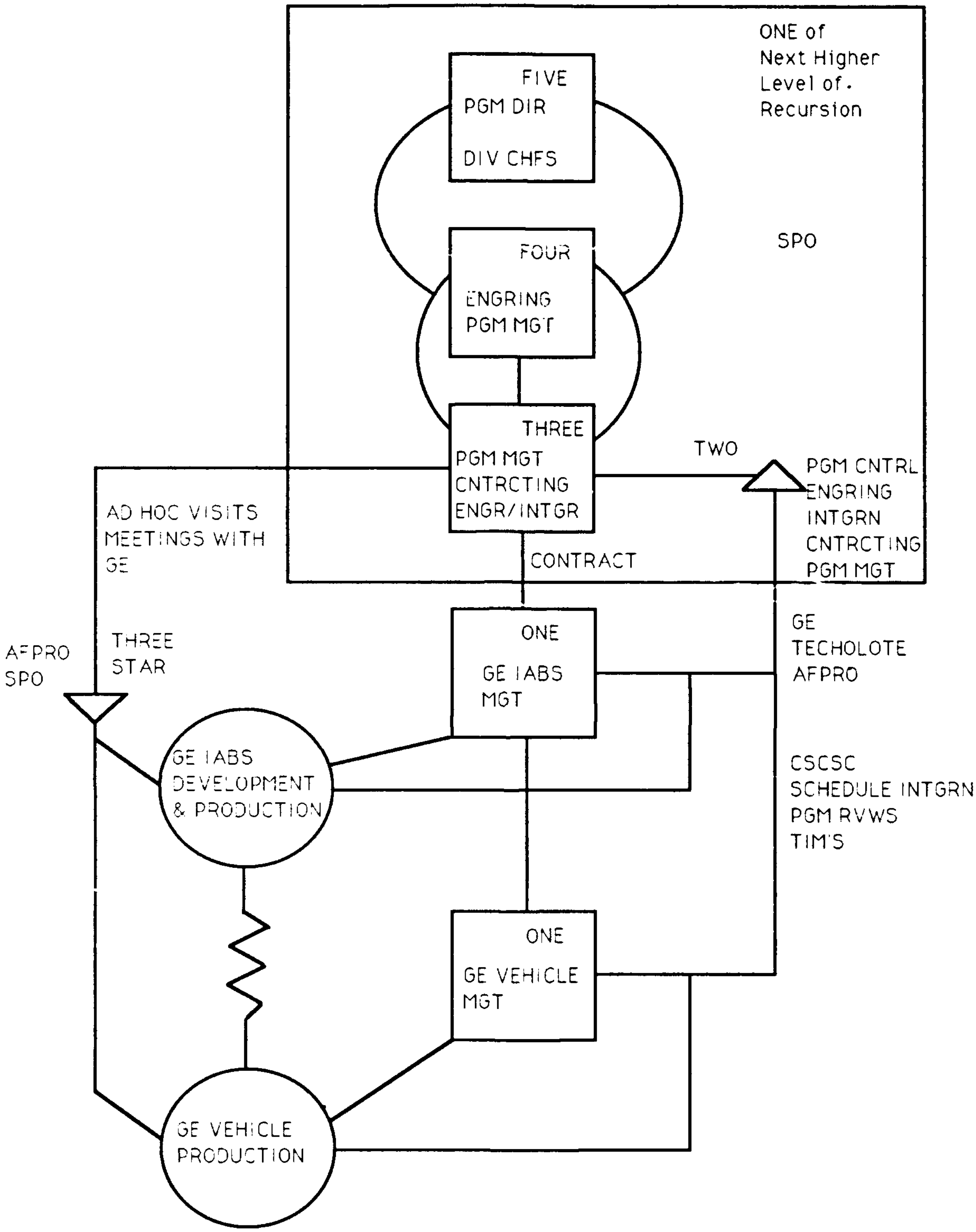
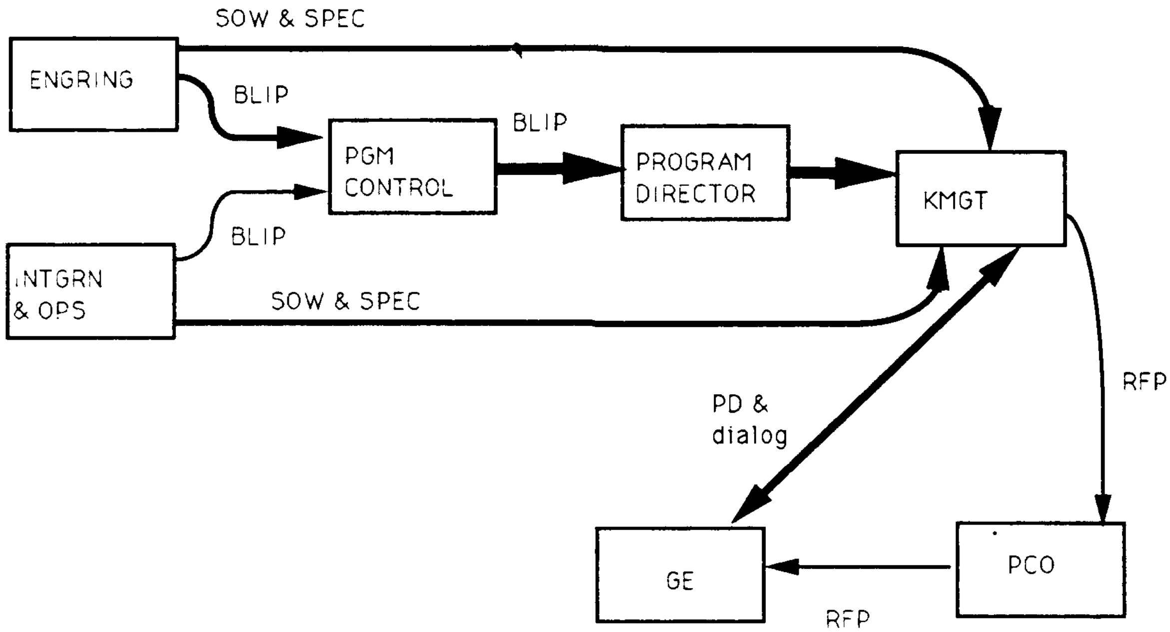


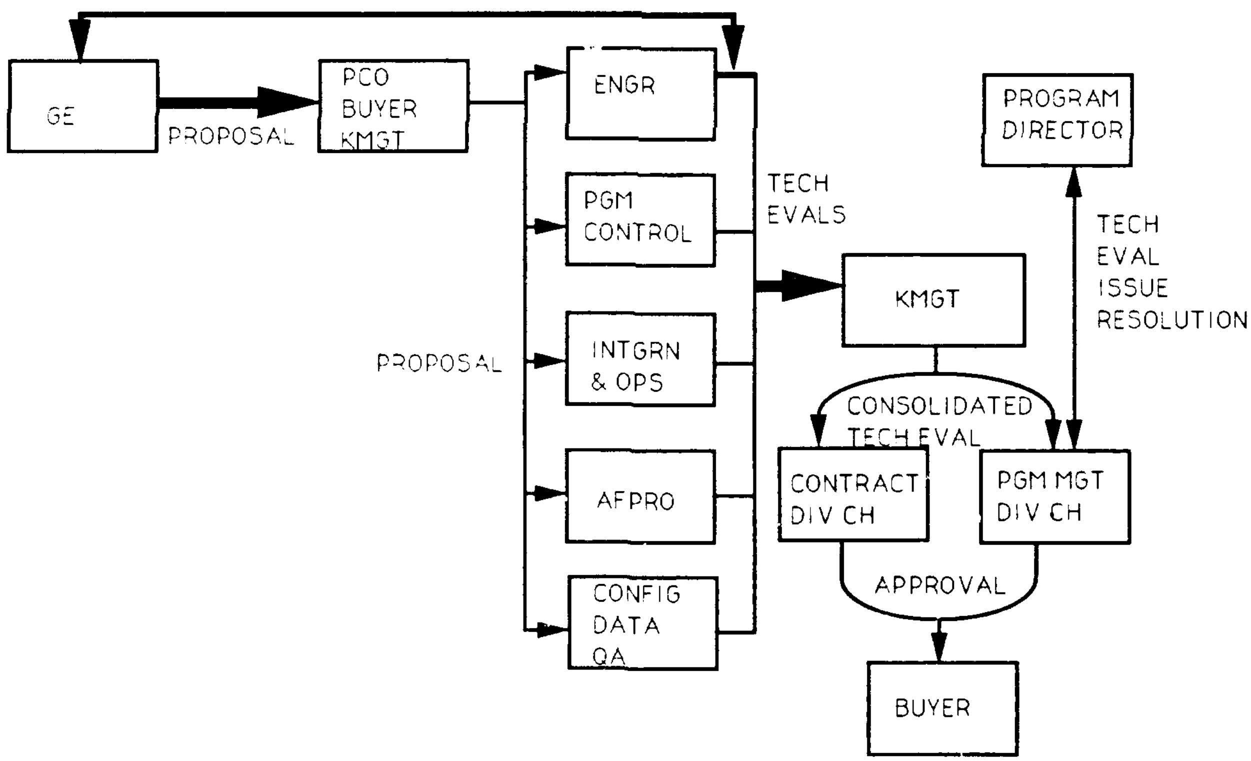
Figure 9. Mapping of the DSCS SPO onto the VSM

bottlenecks within this process and to provide a means to identify possible measures of performance, a QFC of the process has been derived (Figure 10).

The process begins each time SPO engineering (ENGR) or integration and operations (INTGRN & OPS) identifies a beneficial change to the system's design. The change is documented on an internal document called a Budget Line Item Package (BLIP), which includes a description, justification, and reason for the change, a cost estimate, a funding profile required for the change, and approval by the initiator's division chief, the program manager (PM), program control (PGM CNTRL), and the program director (PD). The program director prioritizes and approves BLIPs based on available funding at each bimonthly program review. Once a BLIP is approved, the initiator develops a SOW and specification, designates any necessary CDRL items, and provides the package to the contract management (KMGT) branch which devises an acquisition strategy and drafts an RFP, which usually consists of a letter outlining what is to be proposed and the attached SOW, specification, and CDRL. The RFP is then signed by the Primary Contracting Officer (PCO) and sent to GE. The GE contracting manager issues a Program Directive (PD) providing guidance to those at GE who must provide input to the proposal and provides a courtesy copy to the SPO contracting management branch chief. If any disparity exists between the SPO's intent

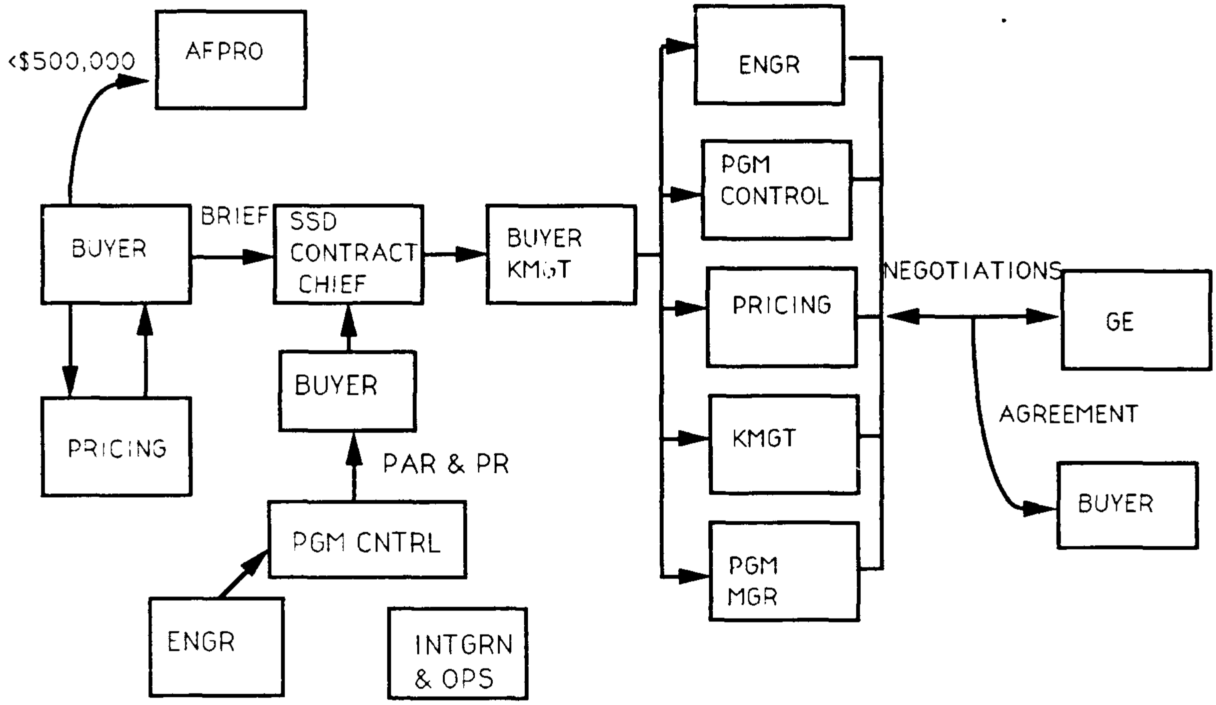


a) Request for Proposal Phase

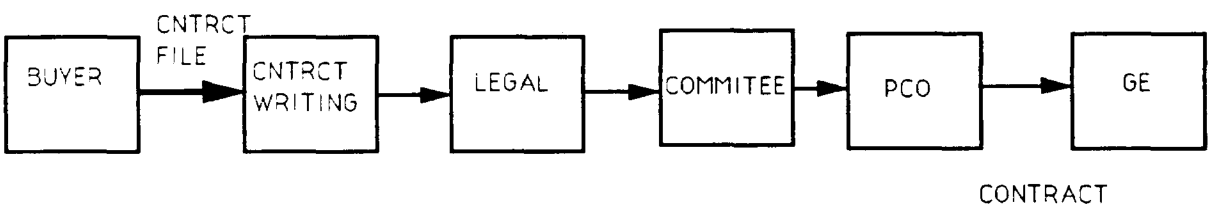


B) Proposal Review Phase

Figure 10 QFC: DSCS SPO Contract Modification Process



c) Negotiating Phase



d) Contract Award Phase

Figure 10. QFC: DSCS SPO Contract Modification Process (cont)

and the PD direction, clarification is immediately provided so that GE does not waste time preparing an unacceptable proposal.

At least five days before the proposal is expected from GE, the government team meets to discuss what proposal is expected, the schedule for proposal review, and any anticipated problem areas. The government team includes everyone who must review the proposal: The program manager, the contracts manager, configuration (CONFIG), data, quality assurance (QA), Air Force Plant Representative Office (AFPRO-GE) personnel, the buyer, and one or two technical representatives (ENGR or INTGRN & OPS). Once the proposal is received, each member of the review team reviews the proposal and identifies questions in need of resolution. These questions are posed to GE, either in a meeting (if time to award is critical) or more usually in writing, to which GE responds in kind, followed by a few days of discussion. The technical evaluation of the proposal by the government team follows, although the most extensive evaluation is conducted by the technical representatives; the contract manager consolidates the results and obtains approval from the contracts and program management division chiefs (DIV CHs).

If the dollar value of the contract is expected to be less than $500,000, the evaluation is forwarded to the AFPRO for negotiation and contract award. Otherwise, the

contracts division obtains pricing of the technical proposal, by applying GE labor rates to the expected manhours and adding profit, general and administrative expenses, and overhead, prepares a pre-negotiation briefing for the SSD contracting division chief. Before he is briefed, a Program Action Request (PAR), AFSC Form 1661, and a Purchase Request (PR), AF Form 9, must be prepared and signed, by various members of the SPO. The result of the briefing is approval to negotiate a contract with GE up to a certain dollar amount. Negotiations are then conducted, face to face, with the contractor; during negotiations, the buyer is the primary spokesperson for the government, but other members of the team are present or on call to provide support.

Once an agreement is reached, the buyer completes his contract file, provides it to contracting staff who write the contract. The contract is then reviewed by the SSD legal office and by a contracts staff committee. Finally, the contract is signed by the PCO and GE, which culminates award of the contract to GE to perform the specified work at the agreed-to price (17).

The frequency and extent of effort identified by the QFC indicates that the contract managers and the buyers are the most likely bottleneck areas within the process. In addition, funding may be a bottleneck, to the extent that there are more modification ideas than there is money

to accomplish them. Also, the QFC highlights the number of unique times each functional area must contribute to each modification effort. Knowing that the number of contract modifications processed by the SPO averages at one or two each month, and that the entire process requires between three and four months to complete under normal circumstances in each case (17), it is obvious that many modifications are ongoing simultaneously, and consequently several are on hold while any one is being worked on any place in the process. A common understanding of the relative importance of each (priority) and a continual dialog among participants are necessary to keep the process moving.

In Figure 10, boxes represent personnel conducting a given functional task and the lines connecting them represent the paperwork which must flow among the functions for each modification. An assessment of the amount of paper flowing through each box, indicated by the thickness of the line, would be helpful to further quantify the process. In addition, it is assumed that each modification must follow the exact same process -- except for the contracts estimated to cost less than $500,000; to the extent that exceptions occur, the percentage of work flowing along any particular path could also be added as well.

Prescription

While continuing research is necessary to gain a complete understanding of the cybernetic forces at work within the DSCS program office, several general recommendations can be made. Specifically, during the author's data gathering, several cybernetically supported ideas were raised by SPO members; since those within the organization are most aware of the actual workings of the SPO their inputs seem the most likely place to begin a process of continual improvement.

First, improved and continual communication among the government team members as BLIPs are prepared, to discuss acquisition strategy, processing priority, funding, schedule, data, and configuration impacts and requirements for the effort is desireable. This interaction would shape team expectations, preclude the need for rework and the probability of any functional area being left out of the loop or working against the planned effort, help team members plan ahead and perhaps more easily balance their workloads, and result in a more informed and participative effort. In addition, by planning strategy as a team first, opportunities to combine efforts might present themselves (17).

Further, the possibility of limiting the paperwork burden was an area of much discussion, the ideal of reporting on an exception basis as discussed in chapter two

notwithstanding. For example, the rationale for having multiple different forms to record similar information was discussed, especially in the costing area. Unfortunately, most of the requirements for funding and program data in specific formats originate outside of the SPO and change would require agreement from SSD and/or AFSC. However, one situation within the SPO presented itself: combining the BLIP and PAR requirements into a single effort to initiate a change (17).

The most desperate need seemed to be for an integrated, but not overwhelming, computer data base. It was reported that historical data was difficult to obtain, that the few separate data bases now in use (three computer systems: Taskfile used by Techolote, PMS for the contracting community, and the SSD/AC performance analyzer, and GE internal system which for the most part is not yet computerized) do not always agree, and that data entry and maintenance of these data bases was very time consuming (17). The best approach to resolve this area of difficulty depends on the amount of freedom afforded the SPO. Efforts already underway include obtaining GE C/SCSC reports on disk to avoid re-entry of the data, use of the PMS system by other functional areas (program control and contract management). However, any truly integrated and predictive data base would have to include computer links with GE to allow real time reporting of anomalies in critical variable

performance and allow access to additional data on demand, and others at SSD, and higher levels within the government to which the SPO must report. Development of appropriate measures and determination of critical variables that can be measured and analyzed in real time to provide for predictive (vice historical) management are considered in the next section of this chapter.

Design of a Cybernetic Measurement and Analysis Tool

Presuming availability of the necessary software, by acquisition or development, and the ability to gather and transmit data automatically and in real time, design of a cybernetic measurement and analysis tool for the SPO consists of identifying the variables to measure, and the points in which processes at which to measure them. The goals of such as system are to control SPO operations and measure SPO and contractor performance to assess performance and stability.

Goldratt's theory of constraints (12:7) provides a means to control and improve any process. By focusing on the bottlenecks and controlling the entire process base on the rate of the bottlenecks, the inventory and operating expense should decrease, while the throughput should increase -- or in terms more familiar to the SPO: the rate (number per unit time) of contracts awarded should increase, while the work waiting (on hold) at any location

for processing is decreased, and less work and time are lost.

To develop a cybernetically based scheduling and measurement system, measurements of throughput, inventory, and operating expense must be taken at each point of concern within the process. A detailed QFC of each process of the SPO would offer preliminary recommendations for measurement points, and consideration of Goldratt's three essential measures of performance provide ideas of what to measure at each of those points.

First, the throughput through each potential bottleneck must be measured daily if possible and analyzed using statistical software described in chapter two to create a databank from which to determine the patterns of processing -- identify what characteristics of an effort dictate the length of time it takes to be processed. As well as identifying the overall process bottlenecks (those with the slowest rate), this analysis also provides the means for accurate predictions of processing time for future efforts and a realistic schedule for each type of modification effort can be developed. Then every other step in the process must be regulated to correspond to the rate of flow through the bottleneck(s). For example, considering the process in Figure 10, the rate of BLIP approval (which would dictate the workload for the remainder of the functional areas) should not be allowed to

exceed the rate at which they can be processed through the bottleneck. Of course efforts to increase the rate of the bottlenecks should now be taken, made easier by an understanding of what characteristics dictate the time to process. Over time, the bottlenecks should improve with effort to the point where other areas become the bottlenecks. This is the means of continual improvement of which Goldratt speaks.

As well as controlling its own workload in a way the maximizes its own performance, the SPO needs to monitor itself as an entity (to allow assessment of its overall performance by its leadership and the next higher level of recursion) on the basis of throughput, inventory and operating expense of the SPO (not its parts). In the case of Figure 10, it is likely that such measures would include the time taken from BLIP approval to contract award (throughput) including some assessment of quality to avoid incentivizing contracting actions focused on speed alone. Assessments of the work in process (inventory: actions in versus actions out) and operational expense (perhaps cost in wasted effort, or poor morale) must also be made to provide a through means of determining performance. However, to track expected versus actual performance of each critical variable, a determination of its value of capability and potentiality must be made as well from which to calculate performance. The shortest time to contract

award might be the capability measure for Figure 10, and what management would like to see ideally could be the measure of potentiality.

The third area of measurement interest to the SPO is the contractor. Remembering that the operational units are a part of two potentially conflicting dimensions of recursion, two sets of measurements may be necessary. To be aware of the motivations of GE, the SPO must require GE tracking of performance developed from daily throughput, inventory and operating expense measures of the operational units in economic terms (sales to the AF and ROI) and programatic terms (cost, schedule and technical performance), automatically, alerting SPO management only when the analysis indicates that an instability seems likely.

In each of these areas care must be taken in the choice of measurements to ensure the effected people are incentivized to perform as management intends. The bane of many measurement systems currently in use is that the incentives for workers contradict with the real needs of the system and they can be manipulated by the workers to "look good" or prove a point, rather than allow an accurate assessment of performance.

Summary

The cybernetic analysis and findings concerning the DSCS SPO is suggestive of the method by which the

cybernetic tools obtained through the literature review can be applied to the AF acquisition arena. The cybernetic viability of the SPO seems threatened by less than optimal short-term planning procedures, the lack of autonomy of the contractor and of the SPO resulting from the relative lack of accountability which can be demanded of management under the current acquisition system, and lack of a measurement system with which to proactively control operations. Results which would likely be found in any SPO. The means to improve the viability of the SPO are available, but require considerable effort, creativity, and freedom from many current legal and corporate requirements.

V. Conclusions and Recommendations

While specific recommendations and conclusions based on the research of the DSCS SPO are contained within the preceding chapter, this chapter will provide a more general consideration of the benefits and stumbling blocks in applying cybernetic principles to the management of government organizations, specifically AF SPOs, and provide recommendations for further research.

Conclusions

The concepts and tools of cybernetics provides a useful theoretical basis from which to assess the current viability of SPO organizations, recommend organizational improvements, control current processes, and conduct informed planning.

Specifically, the research showed that the SPO organization can be mapped onto the VSM to diagnose the viability of the current organization and prescribe changes. Although the depth of analysis was limited by the level of author involvement in the daily operations of the SPO, the analysis and findings has identified several underlying cybernetic mechanisms responsible for current SPO performance. The understanding gained, that the results of the SPO are limited, or in some cases enhanced, by the organization of the SPO, is revolutionary and should provide a first step toward a better understanding of the

means to improve government management (i.e., SPO) performance.

In addition, the techniques of cybernetic control were explored, and suggestive models of their application to a SPO process were considered. A QFC of a process clearly provides a structured means for understanding a process, its bottlenecks, and its critical parameters. Choice of critical measures of performance and implementation of an integrated data base to provide managers access to accurate forecasts of likely changes in performance as well as full historical reporting capabilities is a creative task and one which challenges the current policies of government acquisition, but which may also offer an achievable alternative to the current data overload with which SPO management is faced. While further efforts are required to fully develop an implement scheme within the SPO environment, the potential for proactive management is promising enough to warrant considerable research in this area by government personnel.

The greatest impedance to the development and implementation of a cybernetically sound organization and management scheme within the government is the proliferation of current detailed instructions issued at every level of the executive and legislative branches of government dictating how acquisition must be accomplished and requiring volumes of routine reports to assure each

level that the direction is being followed. Unless programs are given the autonomy to organize and manage as they see fit to meet their responsibilities and are held accountable for the results, the benefits of proactive management will be lessened by the costs of adhering to many cybernetically unviable dictates in concert with the cybernetic concepts and procedures.

Recommendations

In order to develop a general means for SPOs (and eventually other government agencies) to implement the cybernetic principles of organization and management control, further research is required in several areas.

Follow-on efforts by the DSCS SPO to validate and verify the preliminary models of this research, develop additional models for other processes as required, develop the model for SYSTEM FOUR use, and identify critical parameters to measure within the SPO and GE at crucial points in each process of interest to the SPO would be required before a control system could be designed. Next, software would need to be acquired or developed to implement the cybernetic data gathering and analysis tool developed by Beer, discussed in chapter two. Implementation should be conducted prototypically to explore the best means to implement this system for the first time within the USAF. It is recommended that one or more members of the SPO conduct these efforts because of

the detailed information required about the SPO to succeed. However, the support of one or more cyberneticians and statisticians would facilitate the efforts.

In addition, application of the procedure presented in this document, as well as the follow on effort described above, should be made to other SPOs to determine the general applicability of the procedures.

The results of each implementation should be documented, success relative to current practice should be assessed, and policy changes recommended at various levels within the government to coincide more readily with those cybernetic constructs found useful.

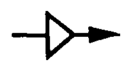
If results prove advantageous, eventually, it should be possible to develop an implementation procedure tailored to each type of government agency and to construct software packages which would provide a relatively simple and straight forward means for any SPO to adopt these techniques.

Appendix A: Glossary of Terms

Actuality — A cybernetic measure whose value is what is typical or expected under current conditions (5:292); "what we are managing to do now, with existing resources, under existing constraints: (2:163)

Adaptability — Ability of an organization to change in concert with it's environment to remain viable; "adjusting oneself to changing conditions (3:135)

Algedonic — "Pertaining to regulation in a non-analytical mode; raising alarm" (from the greek for pleasure and pain) (4:134). For example, an algedonic measure is one of "allrightness" -- a ratio of expected to measured value ranging from 1.0, in which the two values are equal and everything is all right, to 0.0, in which nothing is (5:296)

Amplifier — "A device that increases variety,  " (4:35)

Attenuator — "A devise that reduces variety,  " (4:35)

Attribute — Any property, quality or characteristic of a person or thing

Autonomy — "The freedom of an imbedded subsystem to act on its own initiative, but only within the framework of action determined by the purpose of the total system" (4:105)

Black Box — A theoretical construct in which only inputs and outputs are known -- not what goes on inside -- realistic approximation of a complex system (e.g., baby, corporation) (5:40)

Bottleneck — "Resource whose capacity is equal to or less than the demand placed upon it" (11:137-138)

Capability	A cybernetic measure of what is planned, under current conditions (5:292); "what we could be doing ... right now ... with existing constraints, if we really worked at it" (2:163)
Channel Capacity	"A measure of the amount of information that can be transmitted in a given amount of time" (4:53)
Cohesion	What keeps the SYSTEM ONE subsidiary viable systems a part of the system in focus
Comparator	"A device that compares one numerical value with another" (4:105)
Complexity	Composed of interconnected parts; complicated; intricate
Cybernetics	"The science of effective organization" (4:xi)
Data	"Statements of fact" (5:283)
Dimension	One facet of a system, for which there is a set of recursions
Dynamic model	Model of time-varying interactions (9:50)
Fact	"That which is the case...incorporates requisite variety" (5:282)
Feedback	Information provided to system inputs and processes regarding its output (4:107) "so as to modify its input" (4:105)
Homeostasis	State of equilibrium (1:84) or "balancing through requisite variety" (4:29)
Homeostat	A control device which recognizes and corrects threats to the system not considered by the designer, eg. engine governor (3:290)
Information	Action generating facts or "that which changes us" (5:283)
Invariant	"A factor in a complicated situation that is unaffected by all the changes surrounding it (such as the speed of light or pi)" (4:17)

Inventory	"All the money that the system has invested in purchasing things which it intends to sell" (11:59)
Latency	"The ratio of capability to potentiality" (5:293)
Metasystem	"A system 'over and beyond' a system of lower logical order" (5:134)
Model	A description of a system (18:4)
Multivariate	Involving more than two independent variables (15:5)
Noise	A "meaningless jumble of signals" (5:283)
Operating Expense	"Money the system spends in order to turn inventory into throughput: (11:60)
Oscillation	"Failing to settle down in homeostatic equilibrium, a dynamic system over-corrects itself continuously" (4:71)
Parameter	"Defining characteristics" of a function or population (15:362)
Performance	"Ratio of actuality to potentiality" (5:293) and the "product of latency and productivity" (2:163)
Population	"Any well-defined collection of things" (15:9)
Potentiality	A cybernetic measure of what could be done if changes were made to current operations (5:292); "What we ought to be doing by developing our resources and removing constraints, although still operating within the bounds of what is already known to be feasible" (2:163)
Productivity	"Ratio of actuality to capability" (5:293)
Ratio	A dimensionless measure which allows comparison among dissimilar processes or systems
Recursiveness	"Principle of organizational and interactional invariance" (5:73); every viable system contains and is contained in other viable systems (5:308)

Requisite Variety	The variety a system needs to absorb the complexity with which it is faced (2:392)
Self-Reference	"Property of a system whose logic closes in on itself; each part makes sense precisely in terms of the other parts: the whole defines itself" (4:17)
Simulation	"Process of designing a mathematical-logical model of a real system and experimenting with this model on a computer" (18:6)
Stability	Retaining a state of equilibrium; in control
State	Condition; defined by values of the system's variables
System	"A group of elements dynamically related in time according to some coherent pattern" (5:7)
Time Series	A two dimensional plot of a variable's value over time, the magnitude of the variable plotted on the vertical axis against the time after some arbitrary start time on the horizontal axis -- Statistical Process Control technique.
Throughput	"The rate at which the system generates money through sales" (11:59)
Transcient	System behavior which changes in character over time (9:51)
Transducer	"Encodes or decodes a message whenever it crosses a system boundary -- and therefore needs a different mode of expression" (4:53)
Variety	Measurement of complexity; number of possible states of a system (5:32)
Viable	"Able to maintain a separate existence" (4:17)

Appendix B: SPO Documentation and Interviews

Interviews:

1. Levinson, Capt Julia. Chief, SATCOM Program Office Contract Management Branch. Telephone Interview. Space Systems Division, Los Angeles AFB CA, 4 Sep 89.

2. Grant, Lt Col, Capt Levinson, Lt Ho, et al. SATCOM Program Office. Personal Interviews. Space Systems Division, Los Angeles AFB, CA, 18 Sep 89.

3. Levinson, Capt Julia. Chief SATCOM Program Office Contract Management Branch. Telephone Interview. Space Systems Division, Los Angeles AFB, CA, 13 Mar 90.

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Vita

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13. ABSTRACT *(Maximum 200 words)* This effort considered the application of management cybernetic principles of organizational structure and tools of measurement and analysis espoused by Stafford Beer, in concert with the Theory of Constraints of Eliyahu Goldratt, to the USAF acquisition System Program Office (SPO). An extensive review of the literature was conducted and the theory of cybernetics and constraints were summarized In short, cybernetics identifies the necessary and sufficient structural conditions required of an organization to assure its viability and offers an alternative to current "fire-fighting" management using computer analysis of critical measures of performance to provide accurate short-term forecasts. A preliminary cybernetic analysis of SPO organization and measurement tools was made, using data provided by the DSCS SPO, initial recommendations for improvement were derived from SPO members, and impedances were considered. Cybernetics appears to be a promising aid to program managers, providing insight into organizational structure and offering a means to trulyanticipate, and therefore take action to avoid, problems.

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